Visveswaraya Technological University.

S.J.M. Institute of Technology. Chitradurga – 577502 Karnataka.

Department of Automobile Engineering

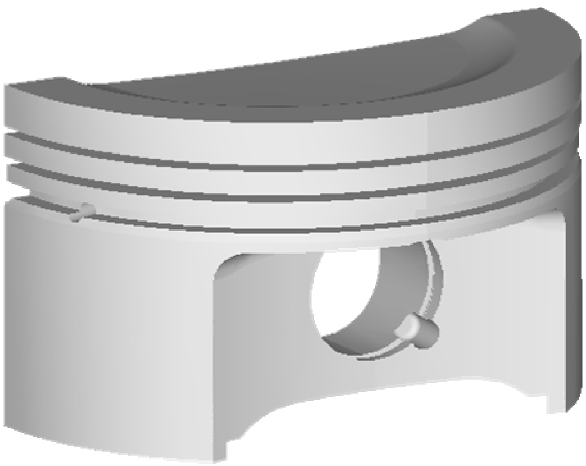
Subject: Theory and Design of Automotive Engines

[Sub Code - AU51]

V – Semester, Automobile Engineering

Syllabus Covered:

1. Piston, piston rings, piston pin, design analysis, methods of manufacture, compensation of thermal expansion in pistons, heat treatment, piston ring selection. Limits of fit for pistons.



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PISTON

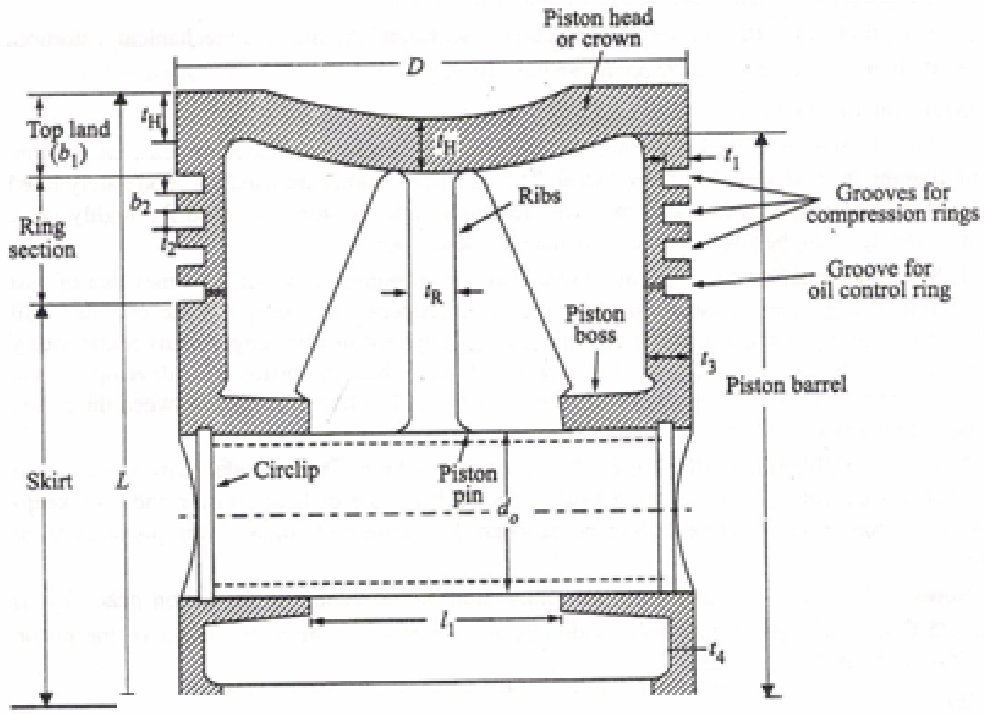
Nicholas August Otto, (German) Inventor of Piston (1866)

Piston is considered to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. The purpose of the piston is to provide a means of conveying the expansion of gases to the crankshaft via connecting rod, without loss of gas from above or oil from below.

Piston is essentially a cylindrical plug that moves up & down in the cylinder. It is equipped with piston rings to provide a good seal between the cylinder wall & piston.

FUNCTIONS:

1. To reciprocate in the cylinder as a gas tight plug causing suction, compression, expansion and exhaust strokes.
2. To receive the thrust generated by the explosion of the gas in the cylinder and transmit it to the connecting rod.
3. To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to obliquity of the rod.



Construction details of Piston

The top of the piston is called head or crown and parts below the ring grooves is called skirt. Ring grooves are cut on the circumference of the upper portion of the piston. The portions of the piston that separate the grooves are called lands. Some pistons have a groove in the top land called as a heat dam which reduces heat transfer to the rings.

The piston bosses are those reinforced sections of the piston designed to hold the piston pin or wrist pin.

MATERIALS:

The materials used for piston is mainly Alluminium alloy. Cast Iron is also used for piston as it possesses excellent wearing qualities, co-efficient of expansion. But due to the reduction of weight, the use of alluminium for piston was essential. To get equal strength a greater thickness of metal is essential. Thus some of the advantage of the light metal is lost. Alluminium is inferior to Cast iron in strength and wearing qualities and hence requires greater clearance in the cylinder to avoid the risk of seizure.

The piston made by the alloy of alluminium produces less inertia forces there by rotating the crankshaft more smoothly. The heat conductivity of alluminium is three-times that of cast iron and this combined with a greater thickness necessary for strength, enables an alluminium piston alloy to run at much lower temperatures than cast iron. As a result carbonised oil does not form on the under side of the piston and the crank case keeps always clean. SAE has recommended the following composition.

SAE 300 : Heat resistant aluminum alloy with the composition, Cu 5.5 to 7.5 %, Fe 1.5 %, Si 5.0 to 6.0 %, Mg 0.2 to 0.6 %, Zn 0.8 %, Ti 0.2 %, other Elements 0.8 %.

Advantages:

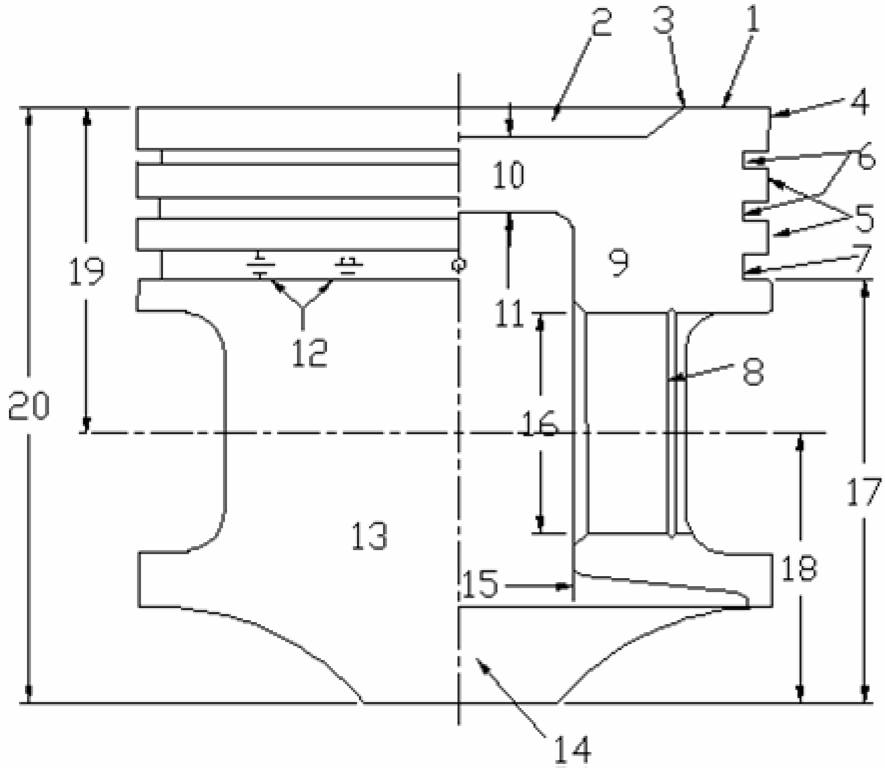
1. Maintain mechanical properties at elevated temperature
2. Heat conductivity about 4.4 times cast iron
3. Specific gravity 2.89

SAE 321 : Low expansion Alloy having the composition, Cu 0.5 to 1.5 %, Fe 1.3 %, Si 11 to 13 %, Mn 0.1 %, Mg 0.7 to 1.3 %, Zn 0.1 %, Ti 0.2 %, Ni 2 to 3 %, other Elements 0.05 %.

Y – Alloy: (Developed by National Physical Laboratory, London.) it is also called alluminium alloy 2285. This alloy is noted for its strength at elevated temperatures. Also used for cylinder heads. Composition of Cu 4%, Ni 2%, and Mg 1.5%.

CONSTUCTION:

A piston is a cylindrical plug which moves up and down in the engine cylinder. It is attached to the small end of the connecting rod by means of a piston pin. Its diameter is slightly smaller than that of cylinder bore. The space between the piston and the cylinder wall is called the piston clearance. The purpose of this clearance is to avoid seizing of the piston in the cylinder and to provide a film of lubricant between the piston and the cylinder wall. The amount of this clearance depends upon the size of the cylinder bore and the piston material because the different metals have different rates of contraction and expansion when cooled and heat.



Piston terminology

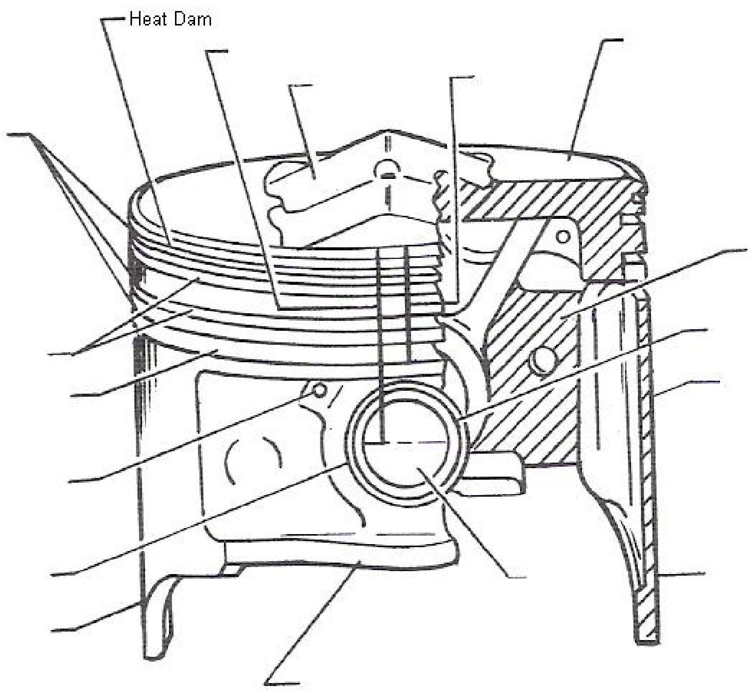
1. Crown,
2. Dish (or bowl),
3. Bowl lip,
4. Top land,
5. 2nd and 3rd ring lands
6. Compression ring grooves,
7. Oil ring groove,
8. Pin retainer ring groove
9. Pin boss,
10. Crown thickness,
11. under crown surface,
12. Oil return or drain holes,
13. Skirt, &14. Skirt tail,
15. Boss spacing, 16. Pin bore diameter,
17. Skirt length, 18. Lower skirt length, 19. Compression height, 20. Total length

PISTON CLEARANCE:

The two different metals having unequal coefficient of expansion which causes engine slap (piston slap). The space between the piston and the cylinder wall is called the piston clearance. This clearance is essential to provide a space for a film of lubricant between the piston and cylinder wall to reduce friction. The piston clearance is required for the piston to reciprocate in the cylinder. There are different methods to maintain the proper clearance to dissipate the heat from the piston. They are explained as below,

1. Providing Heat dam:

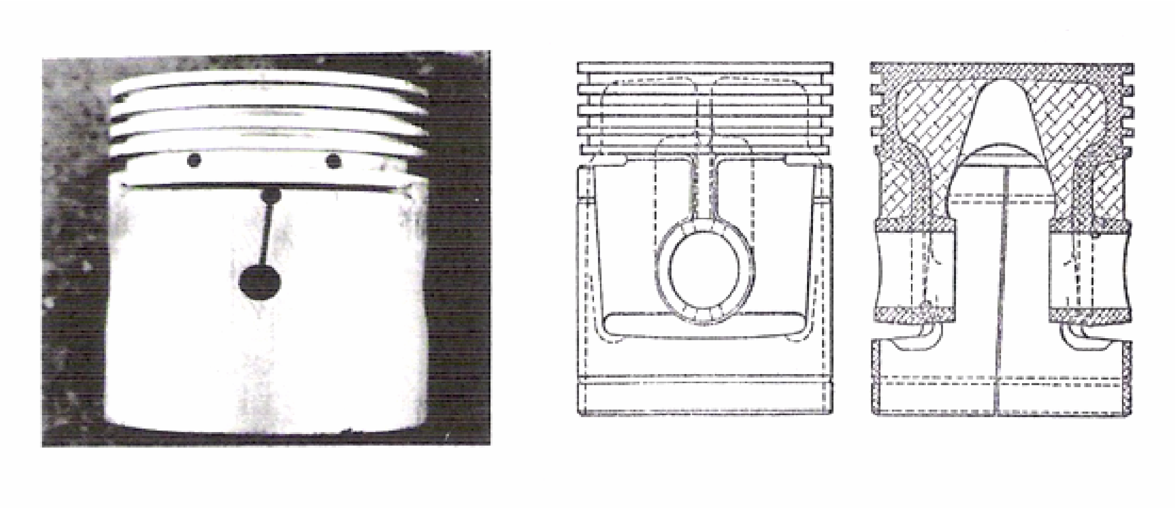
To keep the heat away from the piston skirt or lower part of the piston a groove is cut near the top of the piston as shown in fig. This reduce the path of heat transfer (travel) from the piston head to the piston skirt, there by cooling the skirt and preventing it from expanding in excess.



Piston with heat dam

2. Providing slots:

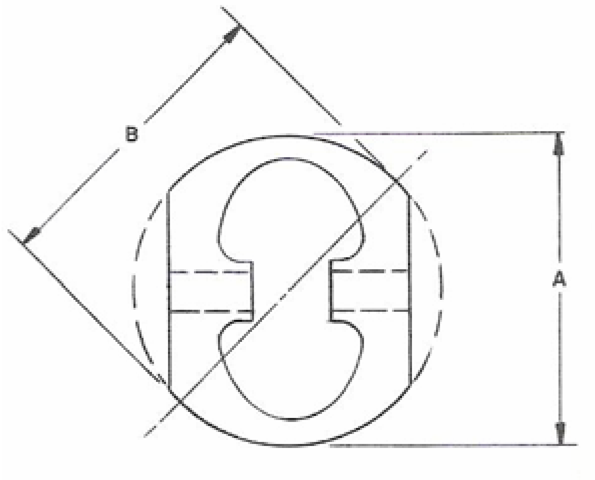
This method is used to control the piston expansion that is by providing slots in the lower portion of the piston. These slots may be horizontal, vertical or T-type as shown in fig. These slots reduce the path for the heat traveling from the piston head to the skirt. Thus the skirt does not become much hot and expands with in limit.



Piston with T-slot

3. Cam – Ground piston:

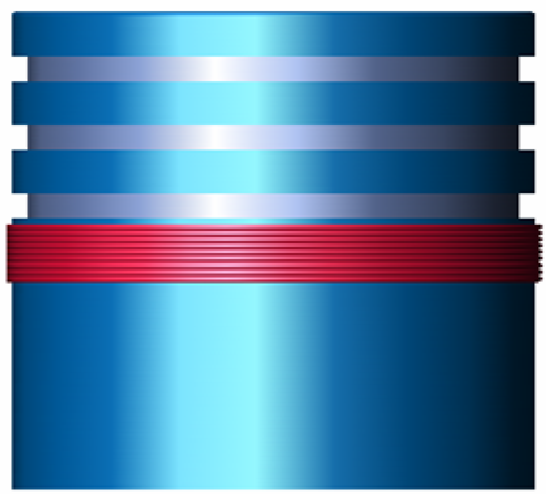
The pistons are finished so that they are slightly oval when cold. These pistons are called Cam – Ground pistons. When a cam ground piston warms up, it assumes a round shape. Its area of contact with the cylinder wall increases. The minor axis of the ellipse lievin the direction of the piston pin axis. Due to providing the bosses for mounting the piston pin in the wall of the piston these is unequal thickness or amount of material with the piston wall. When heated there will be unequal expansion in the piston diameter which gives engine knocks. To overcome this difficulty the pistons are made cam ground in elliptical section instead of circular.



Cam – Ground piston

4. Wire wound pistons:

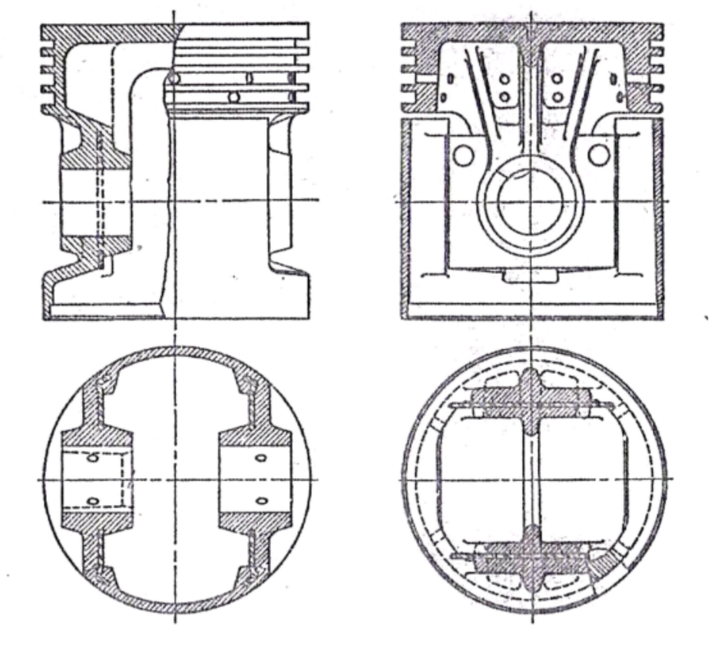
Some of the pistons such as split or cam ground type are provided with the bonds of steel wire between the piston pin and the oil control ring as shown in fig. There by controlling the expansion of the piston skirt to a certain limit.



Wire wound pistons

5. Autothermic Pistons:

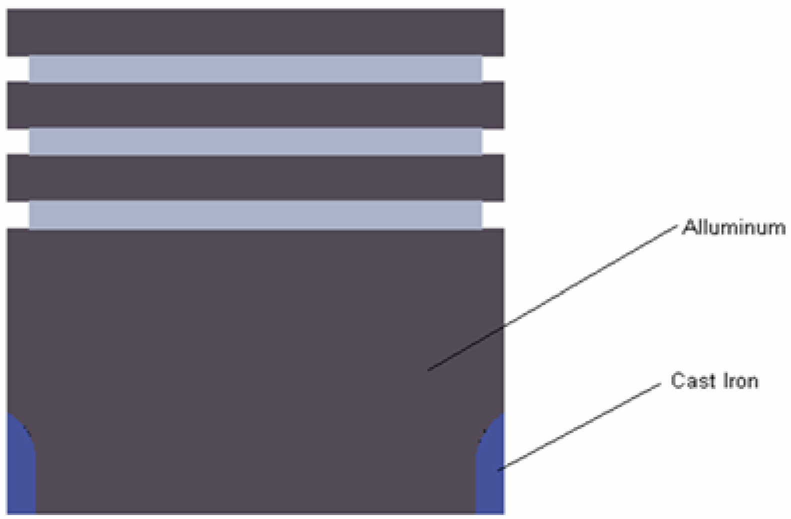
This type of pistons contains steel inserts at the piston pin bosses as shown in the fig. Mostly this piston is cam ground type and the low expansion steel inserts control the expansion of the bosses which are providing along the major diameter of the piston.



Autothermic Pistons

6. Bi – Metal pistons:

This piston is made from two metals alluminium and steel as shown in fig. The skirt is made of steel in which alluminium is casted to form the bosses and the piston of the head. The steel has very small expansion when heated thereby obtaining a smaller cold clearance of the piston.

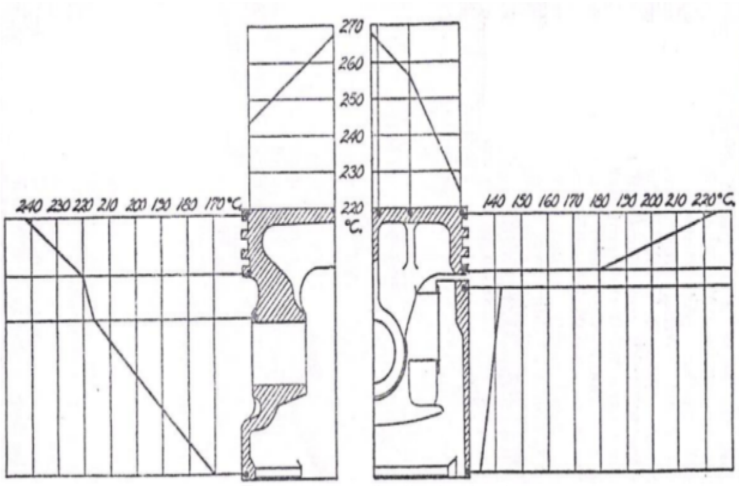


Bi – Metal pistons

7. Special pistons:

The surface of the modern piston are anodized or treated with a coating of zinc oxide or tin. Anodizing is a treatment given to the surfaces of the pistons to resist wear in which the pistons also increase their diameters slightly thereby obtaining a close cold clearance. The special constructions control, the clearance as well as expansion of the pistons in addition to their own advantages. These pistons are oil cooled pistons, pistons with inserted ring carrier, cast steel pistons, tinned pistons etc.

Piston temperature distribution:



Temperature distribution in piston

Piston Production

The first machining operations on a piston of conventional design consists in center drilling the little boss generally provided on the piston head, facing the open end, and boring and chamfering that end. Most of the following opens are located from the center hole in the head end and the finished face and flange of the open end. A no. of turning facing and chamfering operations usually are performed in an automatic lathe in a single setting.

The piston is located from the inside chamfer at the open end and supported by a revolving center mounted in a 4 in air operated tail stock ram. A locating spindle fixture stands extends in to the piston and drives it through the piston bosses. The skirt is cam turned to an elliptic form, from the center of the oil rings grooves to the open end, by carbide tipped tool in a cam turning attachment mounted on the carriage. This tool is mounted in a cam oscillated holder, the movement of which is synchronized with that of the spindle.

Piston must have some desirable (properties) characteristics

1. It should be silent in operation both during warm-up and the normal running.
2. The design should be such that the seizure does not occur.
3. It should offer sufficient resistance to corrosion due to some properties of combustion Ex : Sulphur dioxide.
4. It should have the shortest possible length so as the decrease overall engine size.
5. It should be lighten in weight so that inertia forces created by its reciprocating motion are minimum.
6. Its material should have a high thermal conductivity for efficient heat transfer so that higher compression ratios may be used with out the occurrence of detonation.
7. It must have a long life.

PISTON RINGS

Piston rings are fitted into the grooves of the piston to maintain good seal between the piston and the cylinder wall.

Functions:

1. To prevent the leakage of the compressed and expanding gases above the piston into the crankcase.
2. To control and provide the lubricating oil between piston skirt and cylinder walls.
3. To prevent the entry of lubricating oil from crankcase to the combustion chamber above the piston head.
4. To prevent the deposit of carbon and other materials (matter) on the piston head caused by burning of lubricant.
5. To provide easy transmission of heat from piston to cylinder walls.

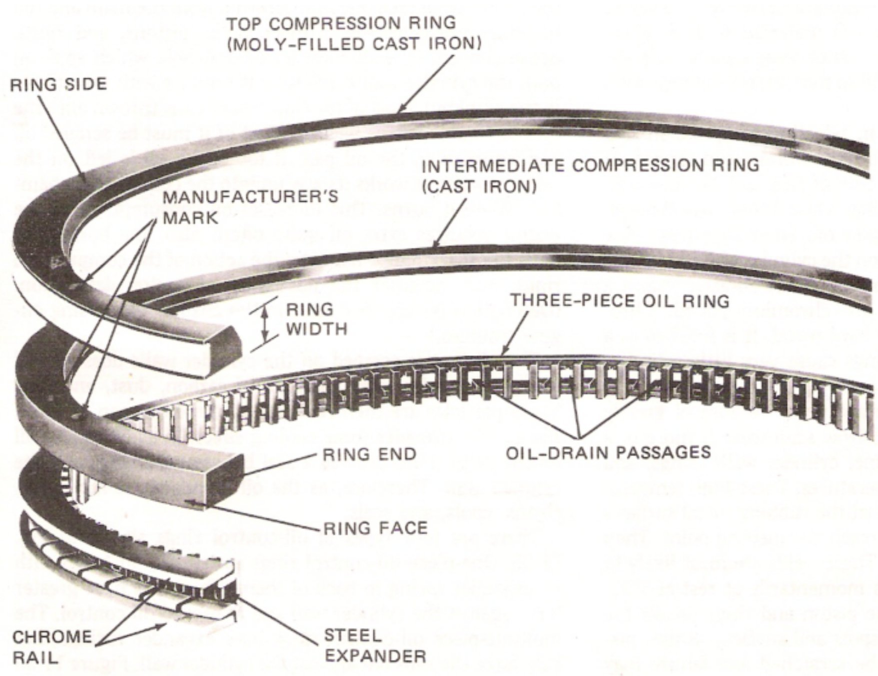
Materials: Piston rings are made of fine grained alloy cast iron. This material possesses excellent heat and wears resisting quantities. The elasticity of this material is also sufficient to impact radial expansion and compression which is necessary for assembly and removal of the ring.

Types of Piston Rings: There are two types of piston rings.

1. Compression rings or Gas rings.
2. Oil control rings or Oil regulating rings.

1. Compression Rings:

Compression rings seal in the air fuel mixture as it is compressed and also the combustion pressure as the mixture burns. The top two rings are called compression rings Fig (a). They prevent the leakage of gases which are under pressure, from the combustion chamber to the crankcase. Figure shows the nomenclature of piston ring (compression ring).



Piston ring nomenclature

The outer diameter of the ring is some what longer than the cylinder bore and the split joint is open.

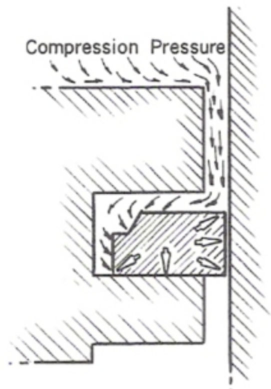
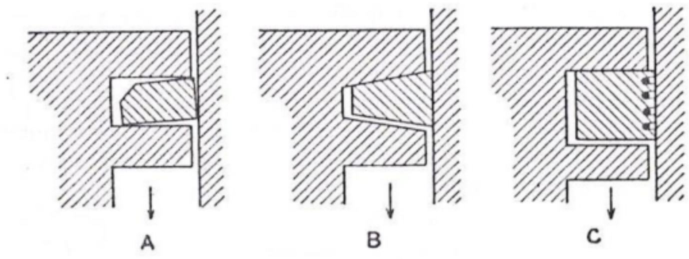


Fig (a) Function of compression ring

Compression rings may have tapered, chamfered, counter bored, scraper, plain or center grooved cross sections as shown in fig.



Types of cross sections of compression rings.

In modern engines there are two or three compression rings fitted into top grooves. The number of compression rings tends to increase the compression ratio. Generally the second and third rings are taper faced and supplied to improve oil sealing. In many engines, counter bored and scraper rings.

Piston Ring Material:

For piston ring we require a material which must be elastic (or resilient), have high ultimate strength, and have provided resistance to wear. Cast iron is the material which meets the requirements. Earlier some CI as used for cylinder blocks, but due to development and continued research special grades of Iron are developed. The typical specification is given for C.I piston rings

Silicon - 2.5 to 2.8, Sulphur - Not over 0.10, Prosperous - 0.5 to 0.7, Manganese - 0.6 to 0.8, Combined carbon - 0.6 to 0.8, Total Carbon - 3.5 to 3.8

Elastic property is required to impart radial expansion and compression which is necessary for assembly and removal of the rings. Ultimate strength necessarily the amount with which it can exert necessary strength against the cylinder wall.

Resistance to wear so that it may have satisfactory life.

Stresses in Piston Ring:

When a ring is inserted in the cylinder it is compressed to a radius which is, of course, the radius of the cylinder bore. If the ring is subjected to plain bending stresses, the compression on the inner fibers equals the tension on the outer fibers and is given by the relationship.

$$\sigma = \frac{E{t_r}^2}{D^2}$$

$\sigma =$ Allowable stress for cast iron, E = Young's modulus of elasticity for the ring material, t_r = Radial thickness of the ring, D = Bore size or cylinder bore dia or

Axial thickness of piston rings $h = t_a \cong (0.7 to 1.0) t_r$

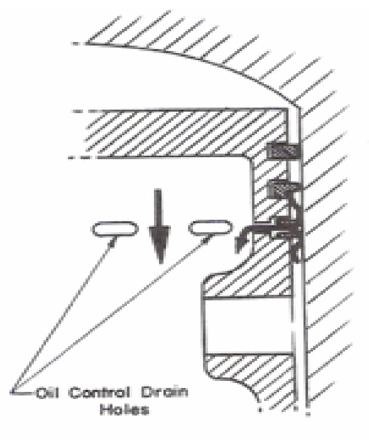
The expression for approximate no. of rings $h = \frac{D}{10i}$

$\therefore i = \frac{D}{10 \times h}$ i = No. of rings

It is desirable to make the rings narrow, to reduce the loss of power due to friction between them and the cylinder wall and probably there will be less wear on the sides of the ring grooves. The disadvantage of having narrow rings lies in their delicate handling equipment. are used for top and second compression ring. During suction stroke the rings twist slightly due to the normal force produced by cutting away a corner of the rings. Thus as the rings move down they scrape off the oil that might have been left on the cylinder wall by the oil control rings.

During compression stroke when the rings move upward, they tend to skate over the oil film on the cylinder wall. Thus less oil is carried up into the combustion chamber. During power stroke because of the combustion pressure the ring untwist and they have full face contact with the cylinder walls. During exhaust stroke the same action takes place as in compression stroke.

3. Oil Control Rings:



Function of Oil Control Rings

Oil control rings scrape off excessive oil from the cylinder wall and return it to the oil pan. Some connecting rods will have an oil split hole which splits oil from the oil pan on to the cylinder wall during each revolution of the crankpin, for more oil reaches on the cylinder wall than is needed. This must be scraped off and returned to oil pan. Otherwise it will go the combustion chamber and burn. This burned oil would foul the sparkplug and increase the possibility of knock. One piece slotted cast iron type oil control ring has slots between the upper and lower faces that bear on the cylinder wall. The oil scraped off the cylinder wall passes through those slots in the back of the oil ring grooves in the piston and from there it returns to the oil pan.

Why two Compression rings and One Oil Control ring?

Usually two compression rings are fitted on the piston. During the power stroke the pressure increases and would be difficult for a single compression rings to hold this pressure. If there are two rings, this pressure will be divided between two rings. The loss of pressure past the upper ring is reduced. The load on the upper ring is also reduced so that it doesn't press quite so hard on the cylinder wall. Wearing of ring and cylinder is also reduced.

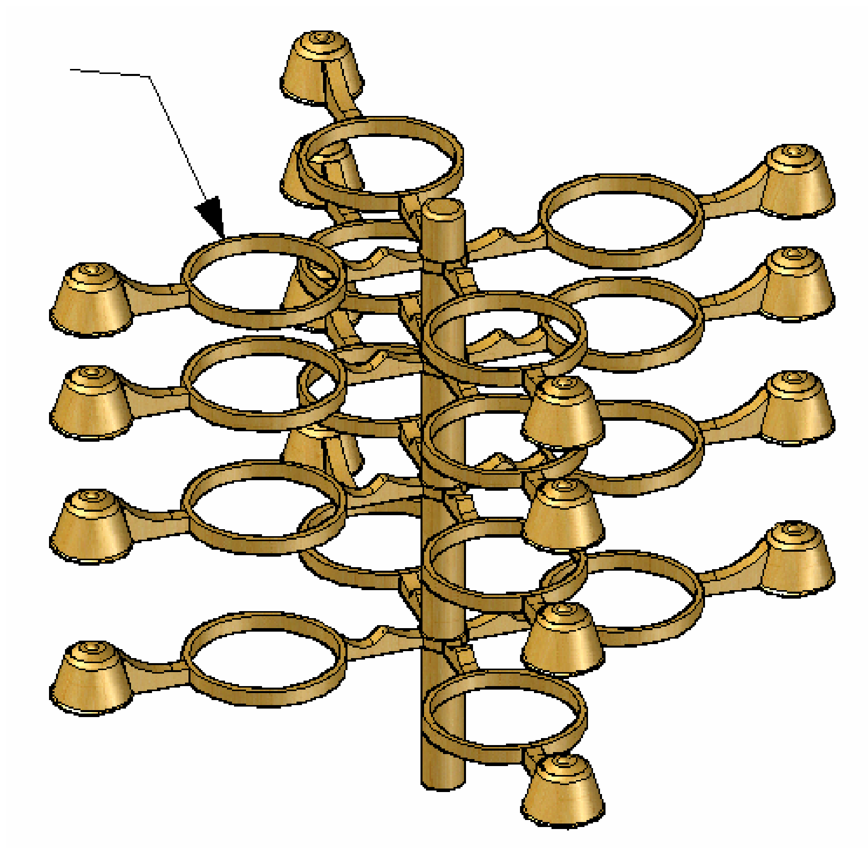
Because of two compression rings are necessary to withstand the high combustion pressure, hence these remains only one oil control ring. It is quite possible to use one oil control ring because of engineering and manufacturing improvements and the more effective action of the modern oil control ring.

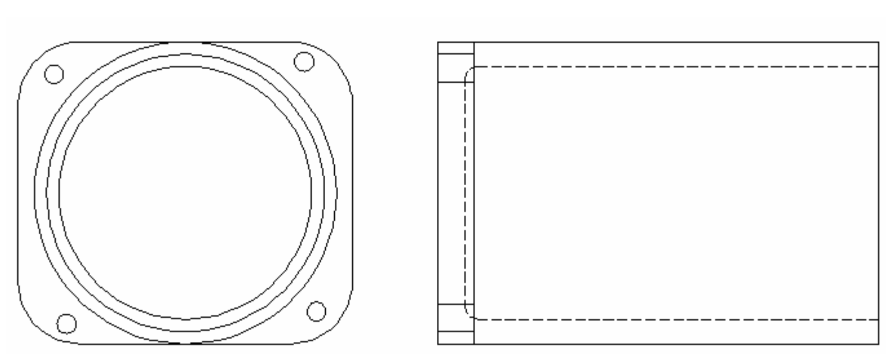
Piston Ring Gap:

Piston rings have gap so that they may be installed into the piston grooves and removed when worn out by expanding them. The gap ensures radial pressure against the cylinder wall thus having effective seal to prevent leakage of heavy combustion pressure. This gap must be checked because if it is too great due to cylinder bore wear, the radial pressure will be reduced. To check this gap clean the carbon from the ends of the ring and then check it with feeler gauge. This gap is 0.178 – 0.50 mm governed by the dia of the bore but if it exceeds 1 mm per 100 mm of bore then, new rings must be fitted.

The gap between the ring and the groove in the piston should also be checked by feeler gauge. This gap is usually 0.038 – 0.102 mm for compression rings and a little less for the oil compression rings. Wear in the piston ring grooves causes the rings to rise and fall during movement of the piston, so causing a pumping action and resulting in heavy oil consumption. Excessive gas blow by, loss of compression will also take place if this gap is too much.

Piston ring manufacture



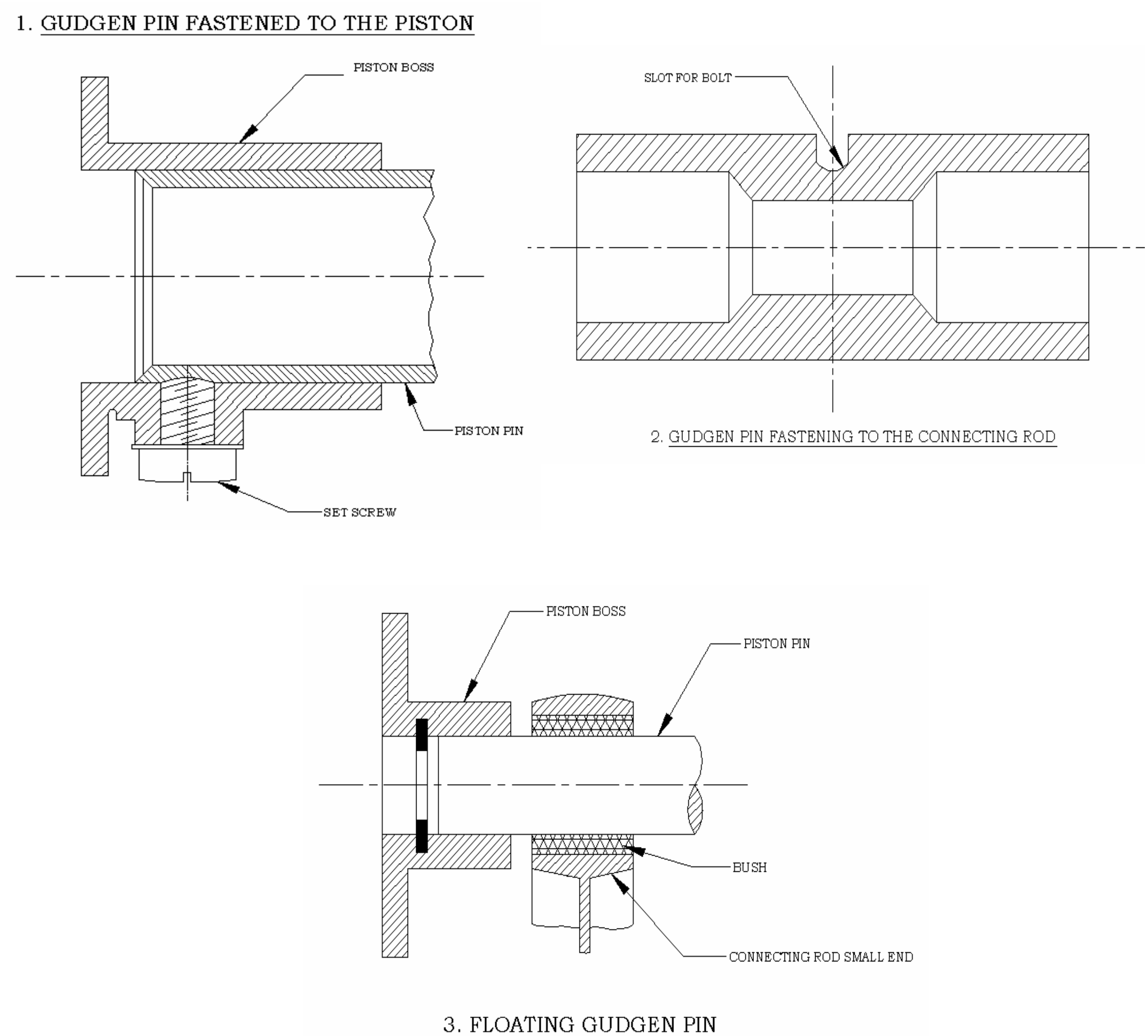


PISTON PIN

Piston pin or gudgeon pin or wrist pin connects the piston and the small end of the connecting rod. Piston pin is generally hollow and made from case hardening steel heat treated to produce a hard wear resisting surface.

There are three methods of connecting piston and connecting rod by the piston pin.

1. The piston pin is fastened to the piston by set screws through the piston boss and has a bearing in the connecting rod, thus permitting the connecting rod end to swivel as required by the combined reciprocal and rotary motion of the piston and crank shaft.
2. The pin is fastened to the connecting rod with a clamp screw. In this case the piston bosses from the bearing. A screw slot is made on the circumference of the piston pin in which the clamp screw is fitted as shown in fig.
3. The pin floats in both the piston bosses and the small end of the connecting rod. It is prevented from coming in contact with the cylinder wall by two lock rings fitted in grooves in the outer end of the piston bosses and these rings are called CIRCLIPS as shown in the fig. This method is widely used. In this case a burning of Phosper Bronze or alluminium is used in the small end of the connecting rod. The bush develops very little wear and requires replacing only at long intervals. In very heavy loading of vehicles of CI engines, special care is taken to avoid risk of fatigue failure cracks. The external bearing surface is finished to a very high degree of accuracy to ensure correct fit in the piston and connecting rod.



Piston pin and connecting rod arrangement

Design of a Piston for I.C Engines

Introduction :

The design of I.C engine piston is probably more subject to controversy than any other machine part or engine mechanism, and any attempt to adhere to rigid rules of design may lead to failure in the first instance.

The shape of the combustion chamber will fix the profile of the piston crown, While, the amount of distortion to be expected and the stresses due to gas pressure will be affected by the shape required.

The rating of the engine and efficiency of combustion will affect the thermal stresses.

The ratio of the connecting rod length to the crank radius will determining the amount of side thrust on the cylinder wall; While, Many factors including the bottom end design (the presence of balance weights on the crank and so on, will influence the no. piston rings and their type).

Procedure :

Piston Head or Crown :

The piston head or crown is designed keeping in view the following two main considerations, i.e.

1. It should have adequate strength to withstand the straining action due to pressure of explosion inside the engine cylinder.
2. It should dissipate the heat of combustion to the cylinder walls as quickly as possible.

The top of the piston may be considered as a flat, fixed on the cylindrical portion of the piston crown and subjected to uniformly distributed load of maximum intensity of gas pressure.

The thickness of the piston top (head) based on the straining action due to fluid pressure is given by (1st condition)

$t_1 = 0.43 \times D \times \sqrt{\frac{p}{\sigma_t}}$ eq. 18.18 (a) ………..pg…….361

t_1= thickness of the piston head

D = Diameter of the cylinder

P = Fluid pressure

σ_t = Allowable tensile stress

The empirical formula, recommended by Held and Favary for the thickness of the piston head is given by,

t_1 = 0.032 D + 1.5 ……mm……………………..eq. 18.18 (b) ……….pg……….361

The thickness of the piston heat based on the consideration of heat dissipation (2nd condition)

$$t_1 = \frac{D^2 q}{1600 \times K \times (Tc - Te)}$$

q = Heat flow from gases ………………………….. J/Sec M^2

$$= \frac{K_1 \times C \times W \times BP}{A}$$

K_1 = A constant representing the amount of heat absorbed by the piston

C = Calorific value of fuel …………… KJ/Kg

W = Fuel consumption ………………. Kg-hr / W

BP = Power …………………… KW

A = Cross sectional area

K = Heat conductivity …………… $\frac{W - mm}{m^2 - {}^0 C}$

$Tc - Te$ = Difference in temperature for that at the center and that at the edge

Design of Piston Rings :

Piston rings are provided at the head of piston. It is advisable to use many narrow rings than using few wide shallow rings.

The radial thickness of the piston rings is given by,

$t_r = D \times \sqrt{\frac{3P_r}{\sigma}}$ ………………….. mm ………….. eq. 18.27 …….... pg……….. 363

P_r= Magnitude of radial pressure on the piston rings ……………. MPa

From T 18.6 …………. Pg. …………….. 366

σ = Allowable stress for cast iron.

The depth of the Piston ring (h)

h = 0.7 t_r to 1.0 t_r

The minimum axial thickness of the piston ring,

$$h = \frac{D}{10 \times i}$$

i = No. of piston rings

Design of Piston pin :

The piston pin is designed for maximum combustion pressure. It is usually hallow to reduce its weight. The center of the pin should be 0.02 D to 0.04 D above the center of the skirt of offset the turning effect of friction. The pin is considered as a simple beam uniformly loaded for a length which is in the connecting rod bearing with supports at the centers of the bosses at both ends. The bosses are at least 1.5 times the outer diameter of the pin. The length of the pin is the connecting rod bearing is about 0.45 D.

Diameter of piston pin (d)

$d = \frac{\pi D^2 P\max}{4 l_1 P_b}$ ……… 18.24 …..... Pg. …….362

$P\max$ = Gas pressure

P_b = Bearing pressure

l_1 = K_1 x d

K_1 = 1.5 for petrol engine

= 2 for oil engines

Problems on PISTON

(Problem No.1)

Design a cast iron piston for a 4-stroke single acting engine from the following data:

Cylinder bore dia = 100 mm (D), Stroke length = 120 mm (L), Gas pressure = 5 MPa, BMEP = 0.5 MPa, Fuel consumption = 0.15 Kg / BP (W), Speed = 2200 rpm. (N)

Solution:

Step 1:

Brake power (BP) .in KW

$$BP = \frac{PLAN}{1000 \times 60} KW$$

$$= \frac{0.5 \times 120}{1000} \times \frac{\pi \times 100^2}{4} \times \frac{2200}{60}$$

$$= 17.275 KW$$

Step 2:

The thickness of piston head is primarily found from its capacity of heat dissipation or consideration of heat dissipation.

$t_1 = \dfrac{D^2 q}{1600 \times K \times (T_c - T_e)}$ mm …………… Eq. 18.19……Pg 361

$t_1 = Thicknessofpistonhead ....mm$, $D = Cylinderboredia.......mm$,

$q = Heatflowfromgases.......J/s - M^2$, K = Heat conductivity ………… $\dfrac{W - mm}{m^2 - ^0 c}$

$T_c - T_e$ = Difference in temperature for that at the center and that of edge.

$q = \dfrac{K_1 \times C \times W \times BP}{A}$ ……….. J/s – m^2

K_1 = Constant representing the part or amount of the heat absorbed by the piston
= 0.05 or 5% [Assume if not provided in problem]

C = Calorific value of fuel [Assume if not provided in problem
= 42000 KJ/Kg substitute in J/Kg inEq.

W = Fuel consumption = 0.15 Kg – hr/KW [Substitute in Kg-sec/KW in Eq]

[If either of or both of C or W are given, need to calculate 'q' or Take q directly from mentioned values in DDHB]

BP = 17.278 ………. KW

A = $\frac{\pi \times D^2}{4}$ = $\frac{\pi \times (0.1)^2}{4}$

= 7.854 x 10^{-3} ……… m^2 [Subs. In equ. In ……. m^2]

$$\therefore q = \frac{0.05 \times (42000 \times 1000) \times \left(\frac{0.15}{3600}\right) \times 17.278}{7.854 \times 10^{-3}}$$

= 192491 J/s-m^2

$\therefore t_1 = \frac{D^2 q}{1600 \times K(Tc - Te)}$ Equ. 18.19……..361

D = 100 mm = Bore dia of cylinder [Subs. In equ. in mm]

q = 192491……… J/s-m^2

K = 460 ……… $\frac{W - mm}{m^2 - {}^0C}$ from Pg. 362

$Tc - Te$ = 222^{0}C…….... for C.I Engine from Pg. 362

$$t_1 = \frac{(100)^2 \times 192491}{1600 \times 460 \times 222}$$

= 11.78 mm

The thickness of piston head based on fluid pressure (stress)

$t_1 = 0.43 \times D \times \sqrt{\frac{P}{\sigma_t}}$ Equ. 18.18 (a) Pg. 361

P = Fluid pressure, MPa = …….. M N/m^2

= 5 MPa

σ_t = Allowable tensile stress ……… MPa ………. M N/m^2

= 38 …….. MPa for close grained CI

D = 100 mm

= 0.43 x 100 x $\sqrt{\frac{5}{38}}$

= 15.597 mm ≈ 16 mm {Adopt great value of t_1}

The thickness of piston head based on an Empirical Formula

$t_1 = 0.032D + 1.5mm$ Equ. 18.187 b Pg. 361

= 4.8 mm

Length of the piston (L)

L = D mm Equ. 18.22 Pg. 362

L = 1.5 D

= 0.75 D mm for aero engines

= 2.5 D mm for stationary and marine engines

= 100 mm

Properties of Piston Rings :

The radial thickness of the C.I Snap ring (t_r)

(from bending stress consideration)

$t_r = D \times \sqrt{\frac{3P_r}{\sigma}}$ Equ. 18.27 Pg. 363

D = Bore dia. = 100 mm

P_r = Magnitude of radial pressure on the piston rings…… MPa

= 0.02746 N/mm^2 (MPa) Table 18.6 Pg. 366

For petrol engines

σ = Allowable stress for Cast Iron

= 82.0 to 100 M N/m^2 …….. N/mm^2

= 82 N/mm^2

$= 100 \times \sqrt{\frac{3 \times 0.02746}{82}}$

= 3.167 mm

The depth of the piston ring (h)

h = 0.7 t_r to 1.0 t_r Equ. 18.28 a Pg. 363

= 0.7 x t_r = 0.7 x 3.167

= 2.22 mm

The distance from top to the first groove (t_g)

$t_g = 1.0\ t_1$ to $1.2\ t_2$ Equ. 18.30 Pg. 363

$= 1.2\ t_1$

$= 1.2\ t_1$

$= 1.2 \times 16$

$= 19.2$ mm

The lands between the ring grooves (t_{land})

$t_{land} = h$ or slightly less than h ($<h$) Equ 18.31 Pg. 363

$= h$

$= 2.22$ mm

The minimum depth of the piston ring

$$h = \frac{D}{10i}$$ Equ. 18.28 b Pg. 363

i = No. of piston rings

$$i = \frac{D}{10h}$$

$$= \frac{100}{10 \times 2.22}$$

= 4 nos.

The maximum thickness of the piston barrel (t_3)

$t_3 = 0.03\ D + b + 4.5$ mm Equ. 18.20 Pg. 363

b = depth of ring grooves…….. mm

$= t_r + 0.4$ mm

$= 3.169 + 0.4$

$= 3.57$ mm

$= 0.03 \times 100 + 3.57 + 4.5$

$= 11.07$ mm

The wall thickness towards the open end of the piston (t_4)

$t_4 = 0.25\ t_3$ to $0.35\ t_3$

$= 0.3\ t_3$

$= 0.3 \times 11.07$

$= 3.321$ mm

Stroke length (L_5)

L_5 = 1.3 D to 1.4 D Eqn. 18.23 Pg. 363

= 1.3 D = 1.3 x 100

= 130 mm

Diameter of the piston pin (d)

$$d = \frac{\pi D^2 P\max}{4 \times l_1 \times P_b}$$ Equ. 18.24 Pg. 362

Pmax = Gas pressure = 5 MPa

P_b = Bearing pressure = …… MPa = …… MN/m^2 = ……….. N/mm^2

l_1 = K_1d

= Length of the gudgeon pin bearing in mm

K_1 = 1.5 for petrol and gas engines

= 2 for oil engines

d = Diameter of piston pin

l_1 = 1.5 d

$$d = \frac{\pi \times 100^2 \times 5}{4 \times (1.5 \times d) \times 15.7}$$

$$d^2 = \frac{\pi \times 100^2 \times 5}{4 \times (1.5) \times 15.7}$$

d = 40.83 mm

Force on piston (F_p)

F_p = P x A

$$= 5 \times \frac{\pi \times 100^2}{4}$$

= 39.27 KN

Check for strength of the piston pin

The bending stress of piston pin (σ_b)

$$\sigma_b = \frac{F_p \times D}{8Z}$$

F_p = Force on the piston …….. N

Z = Section modulus …….. mm^3

$$= \frac{\pi \times D^3}{32} = \frac{\pi \times 100^3}{32} = 98.18 \times 10^3 ....mm^3$$

$$= \frac{(39.27 \times 1000) \times 100}{8 \times 98.18 \times 10^3}$$

= 4.99 ≈ 5 MPa < 62 MPa for carbon steel

(Problem No.2)

Determine the thickness of a trunk type piston for a single cylinder 4-stroke engine developing 11 KW at 600 rpm. The diameter of the piston is 120 mm and maximum explosion pressure is 4 N/mm^2. Heat supplied to the engine is 9505 KJ/KW/hr (KJ/BP). About 6% of the heat is conducted through the piston crown conduction factor for the piston material; material may be taken as 0.046 W/mm^0 C. The temperature difference between the center of the crown and the edge of the crown may be taken as 250^0

BP = 11 KW N = 600 rpm D = 120 mm P = 4 MPa

$T_c - T_e = 250^0$ K = 0.046 W/mm^{0}C $K_1 = 6\%$

Area of Bore,

$$A = \frac{\pi}{4}(0.120)^2 = 11.31 \times 10^{-3} m^2$$

$$= 11.31 \times 10^{-3} m^2$$

Thickness of piston head

$$t_1 = \frac{D^2 q}{1600 \times K \times (Tc - Te)}$$

$$q = \frac{K_1 \times (C \times W) \times BP}{A}$$

$K_1 = 6\% = 0.06$

C x W = Calorific value of fuel x fuel consumption

$$= 9505 \frac{KJ - hr}{KW}$$

$$= 9505 \times \frac{1}{3600} \times 1000$$ [1/3600 because fuel consumption subs. In Kg-sec/KW]

BP = 11 KW

A = 11.31 x 10^{-3} m^2

$$= \frac{0.06 \times \left(9505 \times 1000 \times \frac{1}{3600}\right) \times 11}{11.31 \times 10^{-3}}$$

$$= 154075 J/s - m^2$$

$$t_1 = \frac{120^2 \times 154075}{1600 \times 0.46 \times 10^3 \times 250}$$

= 12.058 mm

(Problem No.3)

Determine the thickness of head of a Cast Iron piston for a single acting 4-stroke engine for the following specification

Cylinder bore = 100 mm

Stroke = 120 mm

BMEP (P_m) = 0.65 N/mm^2

Maximum gas pressure = 5 N/mm^2

Fuel consumption = 0.227 Kg/BP

Speed = 2200 rpm

Calorific value = 41870 KJ/Kg

$$BP = \frac{P_m LAN}{60 \times 1000} KW$$

P_m = Mean effective pressure in MPa

= 0.65 MPa

L = Stroke in M

= 0.120 mts.

$$A = \frac{\pi(100)^2}{4} M^2$$

N = 2200 rpm

$$= \frac{0.65 \times 0.120 \times 7.854 \times 10^{-3} \times 2200}{60 \times 1000}$$

= 22.46 *KW*

Thickness of piston head,

$$t_1 = \frac{D^2 q}{1600 \times K \times (Tc - Te)}$$

$Tc - Te$ = 222^{0}C

D = 100 rpm

$K = 460 \ \dfrac{W - mm}{m^2 - ^0 C}$

$$q = \frac{K_1 \times (C \times W) \times BP}{A}$$

K_1 = 0.05 or 5 % Assumption

Cv = 41870 KJ/Kg = 41870 x 10^3 J/Kg

$W = \dfrac{0.227}{3600} \dfrac{Kg - \sec}{KW}$

A = 7.854 x 10^{-3} m^2

BP = 22.46 KW

q = 377498 $J/s\text{-}m^2$

$$t_1 = \frac{(100)^2 \times 377498}{1600 \times 460 \times 222}$$

= 23.10 mm

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3. High Speed Combustion Engines, P.M. Heldt, Oxford and IBH Publishing Co.
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GLOSSARY

Bowl lip: Edge of the piston bowl as shown in the Figure .1.0.

Compression ring groove: A groove cut into the piston around its circumference, in the upper part of the ring belt. The depth of groove varies depending on piston size and types of rings used.

Compression height: dimension from the pin bore center to the crown excluding any dish or pop up, shown in Figure .1.0.

Connecting rod length-Distance between the centers of the crank pin and piston pin bores.

Cooling gallery: A cast channel in the piston ring belt area that receives cooling oil from an oil nozzle attached to a pressurized oil gallery.

Dish or bowl: Recessed area on the crown. The dish adds clearance volume to the combustion chamber reducing compression ratio. The shape may also enhance combustion.

Groove pound out-A widening of piston ring groove caused by the lower edge of the top ring gap embedded itself to the aluminum .conditions leading to groove pound out include groove wear ,high piston temperatures, and a lower silicon alloy to name a few.

Major thrust face: That portion of the piston skirt which carries the greatest thrust load. This is on the right side when viewing the engine from the flywheel end with the crankshaft rotating counterclockwise.

Minor thrust face: That portion of the piston skirt which is opposite the major thrust face.

Oil ring groove: A groove cut into the piston around its circumference, at the bottom of the ring belt or at the lower end of piston skirt. Oil ring grooves are usually wider than compression ring grooves and generally have holes or slots through the bottom of the groove for oil drainage to the interior of the piston.

Piston crown: Top of the piston. This surface also referred to as the dome, is part of the combustion chamber and some times includes a bowl, pop-up, or valve pockets.

Piston thrust side: The skirt side that absorbs the piston load on the downward power stroke. In engines rotating clockwise this would be left side when looking at the front of the piston.

Piston crown valve pocket: A machined or cast recess on the piston crown to provide clearance to the open intake or exhaust valve.

Piston pins :(Wrist pins or gudgeon pins)

Connections between the upper end of the connecting rod and the piston.

Pins may be held in one of three ways:

1. Anchored in the piston with the bushing in the upper end of the connecting rod oscillating on the pin.
2. Clamped in the rod with the pin oscillating in the piston.
3. Full floating in both connecting rod and piston with lock rings or other devices preventing the pin from contacting the cylinder wall.

Piston skirt taper - The difference between the diameters of the piston at the top of the skirt and at the bottom of the skirt with the diameters being measured in the thrust direction.

Piston pin offset-refers to a condition where piston pin bore center does not intersect with piston axial center .pin offset towards the thrust side of piston can be used to reduce slap noise during piston cross-over in the cylinder bore.

Ports: the inlet or exhaust ports allow air to flow into or out of the cylinder head. Run from the manifold face to the valves.

Power: a measure of the rate at which an engine does work. Numerically, torque multiplied by engine speed, and expressed in horse brake power (bhp).

Ring lands: Section of the piston that supports the piston ring forces. The width of these ring lands affects inters-ring volume.

Skirt: The portion of the piston that provides the bearing surface for side load transfer to the cylinder walls.

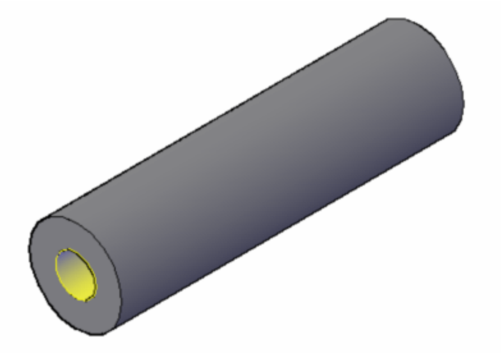
Top land: The ring land above the upper compression ring.

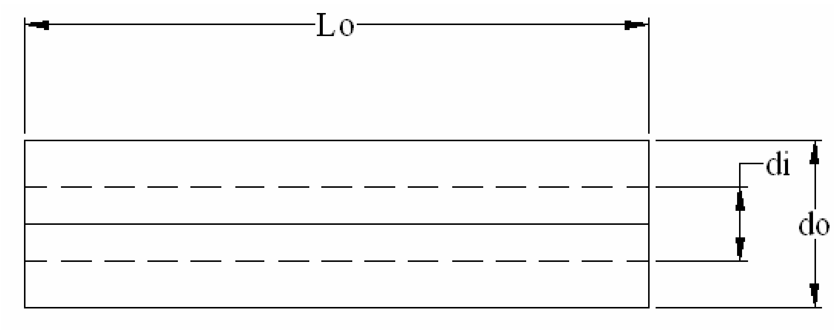
Squish: action of forcing pockets of air within the combustion chamber back towards the spark plug for better fuel distribution.

Stroke: the distance the piston moves up and down within the cylinder bore.

Swirl: horizontal turbulent motion of air entering engine. Helps to give good fuel distribution and improve combustion.

Under crown surface: The under side surface of the crown or dish.

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Outer diameter of pin (based on bearing)

Outer diameter of piston pin is calculated based on bearing pressure length of gudgeon pin bearing l_1 =0.45D to 0.5D [9]

$$d_{p0} = \frac{F_{\max}}{l_1 P_b} \quad \text{--} \quad (2.17)$$

The table 2.5 shows the bearing pressures for different engines

Bearing pressure p_b (MN/m^2)	12.4	For gas engines
	15	For oil engines
	15.7	For automotive engines

Table 2.5: Bearing pressures for different engines

Inner diameter of pin (based on bending)

Inner diameter of pin is determined by considering bending stress due to gas load when loaded uniformly over length and supported at center of the boss [9].

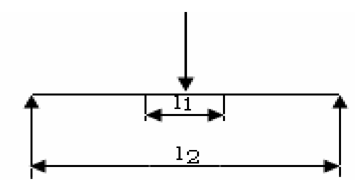

Figure2.12: Bending stress due to gas load

$$Z = \frac{M}{\sigma}$$

But Maximum bending moment M= $\frac{F_{\max} D}{8}$

There fore, by substituting in the above equation

$$Z = \frac{F_{\max} D}{8\sigma_b} \quad \text{--} \quad (2.18)$$

And also, $$d = \left[\frac{32M}{\pi\sigma_b}\right]^{\frac{1}{3}}$$

There fore from above equation

$$Z = \frac{\pi}{32}\left[\frac{dpo^4 - dpi^4}{dpo}\right] \text{ -------------------------------------- } (2.19)$$

The pin inner diameter can be found by equating 'Z'

Requirements of piston pin are

- Adequate rigidity to keep stressing of the piston pin bore and pin bore support at an acceptable level. This rigidity consists of bending deflection and ovalization.
- Adequate rigidity to provide uniform bearing loads in pin bore area.
- Sufficient bearing area from the length and diameter to keep bearing pressure in the piston pin bore and connecting rod bore at an acceptable level.
- Light weight to reduce the effects of inertia forces.
- Good outer diameter and surface finish enhancing lubrication with piston and connecting rod mating surfaces.
- Adequate material and heat treat to provide structural strength and good wear characteristics [3].