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Advances in Manufacture of Piston Rings

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The piston rings in I.C. engines have to perform the following functions:

- ☐ To form a seal for the high pressure gases from the combustion chamber against leak into the crank case.
- ☐ To provide easy passage for heat flow from the piston crown to the cylinder walls.
- ☐ To maintain sufficient lubricating oil on cylinder walls throughout the entire length of the piston travel, minimising the rings and cylinder wear, and at the same time, control the thickness of the oil film so that satisfactory oil control is maintained. The oil is not to be allowed to go up into the combustion chamber where eventually it would burn to leave carbon deposits.

Ring Construction

The construction of a piston ring and the nomenclature of its various parts is shown in fig.1. The ring is generally cast and machined carefully so that when in position, it is able to exert uniform pressure against the cylinder walls. A gap has to be cut out at the ends so that while inserting the ring into the piston, it can be expanded, slipped over the piston head and released into the ring groove. Further, the gap is almost closed when the piston is inside the cylinder, due to which the ring is able to exert pressure on cylinder walls, which is a must for sealing purpose. Moreover, any circumferential expansion of the ring at higher operating temperature may also be accommodated by the end gap. Some differential expansion of the ring with respect to the cylinder is always likely to occur inspite of the equal coefficients of cylinder and ring materials due to the fact that the ring is always operating at higher temperatures than the cylinder walls, that is why direction of heat flow is from the rings to the walls.

The sealing action of the top ring is due to the fact that the high pressure in the combustion chamber presses the top ring tightly on the base of the pisiton ring groove, thus seating the ring. However some leakage does take place through the end gap of the top compression ring. This leakage is useful in that it provides the pressure for sealing action of the second pistion ring, where the sealing action take place in the same way as in case of the top compression ring.

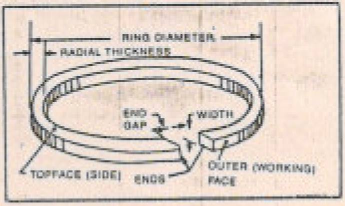

Fig. 1 Ring nomenclature

The amount of end gap should, however, be determined cautiously. Excessive end gap would result in blow-by and scuffing of the rings. On the other hand, lesser clearance would cause the ring ends to butt at higher temperatures, resulting in excessive and non-uniform pressure on the cylinder wall, causing excessive wear. In practice piston ring end gap, when installed, is kept about 0.30 to 0.35mm.

The ring end gaps may be either strainght butt type or tapered or seal cut type as shown in fig.2. Out of these butt type is most common mainly on account of its economics.

Factors Affecting Ring Selection

The knowledge about the following factors is necessary to select rings for a particular engine:

- ☐ Dimensions of engine block
- ☐ Piston design
- ☐ Piston displacement
- ☐ Piston speed
- ☐ Cylinder bore material
- ☐ Carburation
- ☐ Bore to stroke ratio
- ☐ Compression ratio
- ☐ Cooling capacity
- ☐ Crankcase pressures
- ☐ Engine performance expected
- ☐ Horse power requirement
- ☐ Type of cylinder bore lubrication
- ☐ Peak manifold vacuum.

Types of Rings

The piston rings are of two types:(i) Compression rings and (ii) oil control rings.

The top compression ring (i.e. the ring nearest to the combustion chamber) has to do the hard work of gas sealing and transfer of heat from the piston

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crown to the cylinder walls. The compression rings perform a double role. They seal and transfer heat, and also assist the oil rings in controlling oil.

The function of the oil control rings is evident from their name. To perform this function effectively, they must prevent excessive amounts of oil from passing:

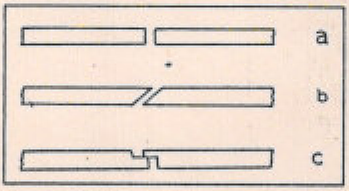

Fig.2 Types of piston ring end gaps
a) Butt type (b) Tapered type
(c) Seal cut type

- Between the ring face and the cylinder wall
- Through the ring end gap
- Around behind the ring.

Design Considerations and Modifications

Number of rings:

The number of rings to be used on a piston varies depending upon the requirements. Earlier two to four compression rings and one to two oil control rings were used, but with modern design trends of decreased car and engine heights, the number of rings is restricted to usually three, out of which one is the oil control ring.

A minimum of two compression rings are required because of the high pressure difference between the combustion chamber and the crankcase at the beginning of the power stroke. This difference may be as high as 70 atmospheres. A single piston ring cannot take such high pressure, which necessitates the use of at least two compression rings, which divide the pressure between themselves. Increasing the number of rings (which is restricted the maximum piston height) also reduces the design pressure between the rings and the cylinder walls which result in decreased wear and consequently increased life.

Compression rings

Rings width:

The trend is towards reducing ring width. During the part five decades, the ring widths have been reduced to about half (to about 1.5mm). Coupled with advantages of reduced ring width are also its disadvantages.

Advantages:

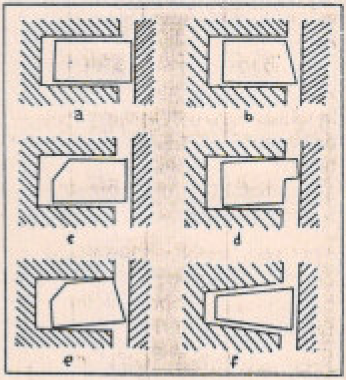

Fig.3 Compression rings a) Plain
(b) Taper face (c)Torsional twist
(d) Scraper type torsional twist
(e) Taper face torsional twist
(f) Key stone

- Good resistance to ring scuffing
- Lower piston height and consequently lower engine height.
- Good resistance to ring flutter
- Problems of ring interia are reduced.

Disadvantages:

- Machining very narrow grooves in the piston accurately is difficult.
- Rings with too much reduced width and without a satisfactory thickness/width ratio become unstable in the ring grooves.

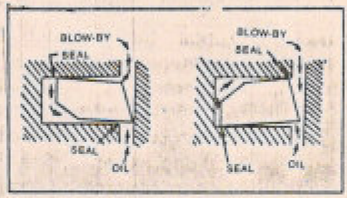

Fig.4 - Twist rings (a) Action of reverse twist ring (b) Action of posive twist ring

Shape

The basic ring shapes in present day use are given in fig.3. The advantage of the taper face, fig 3(a), over the plain ring,fig 3(b), is that it reduces the contact with the cylinder wall to a narrow line, which affords high unit loading on the face of the ring to accelerate ring seating. It also provides a downward scrapping action which results in relatively good oil control. Machining of the inside upper corner makes it a torsional twist ring as shown in fig 3 (c). The internal forces are charged due to machining,so, that when it is installed in the cylinder, it turns about its axis so as to provide a line contact between the ring, and its groove and also contact with the cylinder wall at its lower edge which contributes towards a better control of passage of both the combustion gases and the engine oil. The scraper type torsional twist ring fig.3(d) functions like the bevelled torsional twist ring. However, due to its narrow face, it has advantage of the higher unit face loading in the untwisted position. The taper face, torsional twist ring as shown in fig 3(e) is a combination of the taper face and torsional twist designs. Key stone rings, fig.3 (f) have inclined side faces and operate in grooves of similar geometry. Relative movement between the ring and the groove in the transverse direction discourages the build up of carbon deposits and therefore prevents ring stock. Rings of this form are most commonly used for top for the ring in turbocharged engines.

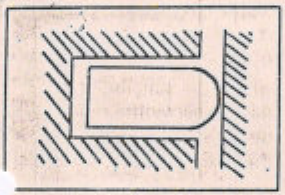

Fig.5 Radius face ring

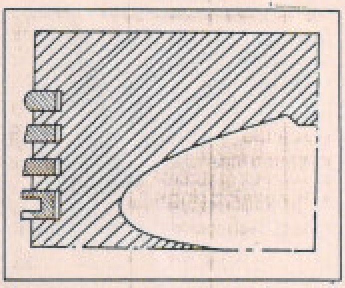

Fig. 6 Rings used in diesel jeep MM-540 DP

A recent modification of the torsional twist ring is the reverse-twist ring (fig 4(a)) whose lower inner edge is bevelled instead of the upper inner edge in case of torsional twist ring. Also the outer face of the ring is tapered to compensate for the twist which is in opposite direction so that in case of normal positive twist ring as shown in fig 4.(b), the reversed twist ring offers better oil control than a normal twist ring, but the later affords better blow by control.

Another recent improvement in compression ring design, which has become quite popular is the radius-face ring, (fig.5). The advantage of the radius shape is that there is high unit loading due to the narow-line contact and secondly the contact with the cylinder wall remains in tact even if the piston ring groove straightness is slightly off. Further, this contact is not lost even when the ring changes direction at the extreme of its stroke when a rocking action can take place. Thus, it results in good oil and blow by control on high speed output engines. Moreover, the wear at the top of the cylinder wall where the top ring changes directions is also reduced. The radial face ring may be bevelled to make it positive twist or reverse twist if so desired.

In India radial face ring has been used for the first time as top ring in the diesel engine DP-4.90 of Mahindra Jeep M M 540 DP (Fig.6).

Rings for worn cylinders

An ordinary piston ring meant for correctly bored cylinder will not work efficiently if fitted in a bore which is worn oval. In such cases, spring expander piston ring may be employed. They may be two-piece, three-piece or four-piece type. Spring expanders are made of spring steel with crimps spaced uniformly along the circumference. The outer cast iron ring exerts only a part of the total pressure on the walls, the rest being contributed by the spring expander which is put inside the outer cast

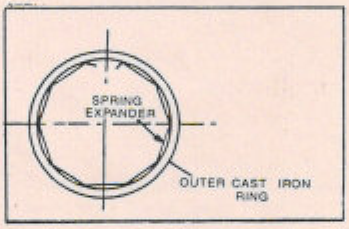

Fig. 7 Spring expander piston ring

Table 1
Typical Ring Materials

Sl No.	Material type and structural characteristics	Composition	Tensile strength MN/m²	Breaking strength MN/m²	B.H.N	Thermal set
1	Centrifugally cast, medium phosphorous pearlitic grey iron. Free ferrite 10% max.	C 3.5 Max., si 1.8-2.5, p 0.4-0.65	247	338	230 - 295	12.5
2	Centrifugally cast, semi malleablised carbidic alloy iron, pearlitic with free carbides and tamper carbon.	C 2.8-3.1,si 1.9-2.5, p 0.3-0.45, Cr 0.75-1.15, Mo 0.8-1.0	402	550	269 - 305	6.5
3	Statically sand cast, Medium phosphorous pearlitic grey iron type A Graphite Free ferrite 5% max	C 3.0-3.3, si 1.4-2.2, p 0.35-0.55, Cr 0.4 max	247	338	200 -245	10.5
4	Individually cast, medium phosphorous pearlitic grey Iron, type A/B graphite,free ferrite 10% max.	C 3.4-3.9, si2. 1-2.9, P 0.4-0.8, Cr. 0.4 max	275	375	230 - 295	20.0
5	Centrifugally cast. Malleabilised fine pearlitic or martensitic low phosphorous iron with temper carbon. high strength and ductility	C 3.0-3.3, si 1.0-1.4, p 0.1max Cr. 0.07-0.3	586	803	230 - 300	12.0
6	Centrifugally cast. Martenstic sphenodal graphite iron No free ferrite	C 3.0-3.65, si 1.7-2.7, P 0.1 max, S 0.03, max, Mo 0.35-0.65, Cu 0.35-0.65, Mg 0.03.-0.07 Ni 0.8-1.7	850	1160	272 - 437	18.0

(Thermal set = % gap collapse when ring closed to nominal cylinder dia for 6 Hors at 350°C)

iron one, (fig.7). In three piece type, apart from the cast iron ring and spring expander, a spiral steel side rail consisting of two turns of thin flat steel is located below the cast iron ring. In four-piece type, there are two such side rails placed one below and the other above the cast iron ring. This type of ring adapts itself to the irregularities of the cylinder bore due to comparatively better flexibility of the ring and also radial pressure exerted due to the internal spring expander.

Oil controlled rings

Commonly used oil control rings are shown in fig.8. Recent research has shown that for performing its functions properly, the oil control ring apart from having increased ring tension and reduced ring cylinder wall contact area, must conform to the cylinder wall. From this point of view, steel expander type of rings are most appropriate.

Few such rings are shown in fig.9. The ring shown in fig.9(a) is equipped with polygonal flat strip steel expanders bearing on the bottom of the piston groove. These rings are ideal for use in chrome-plated bores. Having independence of groove depth, conformable oil rings (fig.9(b)) have high comformability but require sufficient back clearance for ventilation. Loading is achieved by circumferential abutment of the expander which may be either axially crimped or a coil spring.

Materials

The material generally used for piston rings is fine-grained alloy cast iron containing silicon and manganese. It has good heat and wear resisting qualities. The hardness on rockwell B scale is about 100. Some piston ring materials are given in table -1.

Alloy steel have also been used as ring material. Chromium plated rings which have resulted in considerable saving in cylinder bore life. Chromium itself is very hard due to which it is normally expected to wear

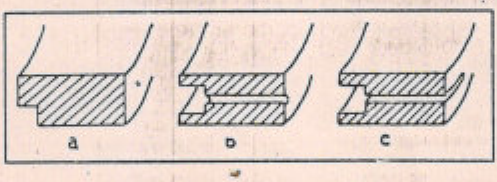

Fig.8 Oil control rings. a) Scraper (b) Drilled (c) Slotted

the cylinder walls rapidly. Yet it does the trick because of very fine finish of its coating on the ring. Chromium plating further helps the rings to resist scuffing because it is difficult to be welded to cast iron cylinder. However, these rings should not be used when the cylinder bore itself is lined with chromium or any such hard material.

Rings with molybdenum-filled face have also been introduced recently. The molybdenum surface has larger oil carrying capacity. It, therefore, provides better cylinder wall lubrication with resultant longer engine life. The higher melting point of molybdenum (2620°C) enables the ring to stand higher temperatures than other ring metals and thus resist scuffing. A more recent development is thermochemically treated chromium C chrome) especially suited for top ring applications where lubrication is marginal.

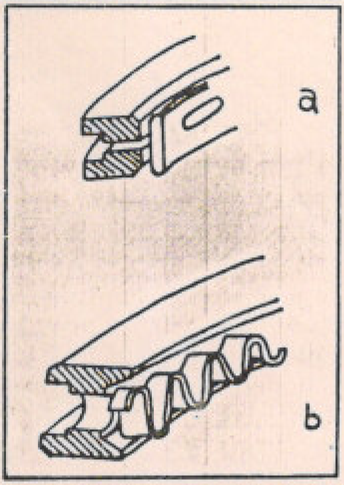

Fig. 9 Oil control rings.
a) Flexoil ring b) Conformable ring

Stainless steel oil rings resist pitting and corrosion to remain clean and do not clog with carbon as quickly as other rings. Further, these resist excessive tension loss at engine operating temperatures.

Conclusion

Advanced engineering designs and newly developing materials may reduce/eliminate piston ring failures (viz. rapid wear, scuffing and beakage) and increase over-all efficiency of internal combustion engines. The use of radius face ring, the wear at the top of the cylinder wall where the top ring changes direction is reduced. Rings with molybdenum filled face and thermochemically treated chromium rings are especially suited for top ring applications where lubrication is marginal. EA

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