Piston Rings

Piston rings seal the bores against combustion pressures and prevent oil entering the combustion chambers. But how do they perform these functions?

*By Nigel Tait**

1. Top Rings

The most popular type of top rings used for passenger car engines over the last 30 or so years is invariably made from a high strength cast iron known as spheroidal graphite iron (ie SG iron for short).

SG iron is very strong and ductile and is chosen because of its wear resistance and strength to resist breakage under the arduous environment of the top ring groove in a piston. The name 'spheroidal graphite' describes the way the graphite particles in the microstructure of this material are formed into spheres, as opposed to the plate or lamellar graphite flakes in normal cast iron. Because of this structure, the material resists cracking, whereas the flakes in normal cast iron act as stress concentrators which makes it very weak in bending or in tension.

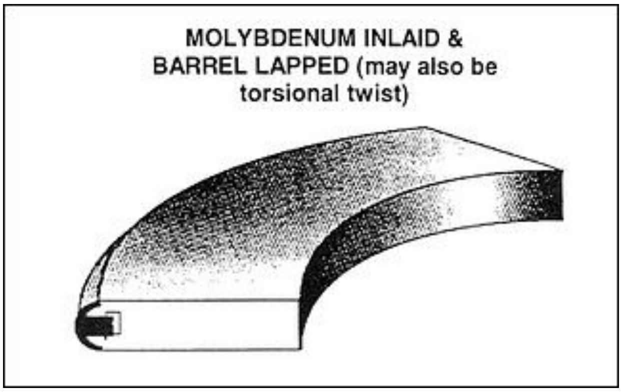
SG Iron Rings

SG iron material needs to be coated on its outer diameter surface to resist wear and scuffing.

On its own, this material is unable to run directly in a bore. There are two types of coating applied to these rings:

- Chromium plating

The ring is plated on its outer diameter surface with chromium to a depth of around 0.1 mm. The surface is then lapped in a pot to get a slight barrel profile and to achieve light-tightness. Chromium plating provides a very hard and wear-resistant surface.



- Molybdenum

The ring is machined with a shallow groove on its outer surface and this groove is filled with molybdenum either by means of wire spray or plasma spray (the latter uses molybdenum in powdered form). Molybdenum is a very hard material and it is extremely wear and scuff resistant. It is more scuff resistant than chromium partly due to the slightly porous nature of the surface which absorbs oil. There are instances where chromium will scuff and molybdenum will resist scuffing in the same engine. It is possible to molybdenum coat the entire outer surface rather than just in a groove - this will depend upon the technique employed by the ring manufacturer.

Steel Compression Rings

Over the last 10 or so years, in many new engines steel has been used as a top ring material instead of cast iron. The reason for this is that it is easier to achieve the very narrow widths that are becoming common, and also the radial depth can be reduced to make the ring more conformable to out-of-round bores. The rings are very strong and wear resistant. However, like SG iron, they need to be treated on their outer diameters to prevent scuffing and wear. Again, like cast iron top rings, steel top rings can be chromium plated or molybdenum inlaid (the steel is pre-grooved when it is drawn), or it can be full face coated with molybdenum using a plasma spray process.

In addition it is possible to nitrocarburise steel rings. This process hardens the whole of the ring, ie its OD surface as well as its sides, so the resistance to side wear is also enhanced. Nitrocarburising is carried out in a liquid bath or in a gaseous atmosphere. As with the cast iron rings, the nitrocarhurised steel rings are lapped in a pot to achieve a slight barrel profile and light-tightness.

There is a difference between the types of steel used for chromium or molybdenum coated rings, and that used if the surface is to be nitrocarburised. If the outer surface is be coated with chromium or molybdenum, there is no need to have a heat-treatable steel - so a steel with low alloy content is normally used. If the ring is to be nitrocarhurised, the steel needs to be higher in chromium, nickel and other alloying elements to facilitate heat treatment.

Steel top rings are now used in the vast majority of new engines. However for most engines being built up for performance applications in the after-market, cast iron rings are generally chosen since they are in fact more ductile than steel, and it is possible to file back the gaps for file-back applications.

Compression Ring Design

For a compression ring to perform adequately, it is essential that it exerts some pressure against the cylinder to maintain a light seal. When combustion occurs, the combustion gases cannot pass this light seal between the cylinder and the ring. The high pressure gas enters the ring groove and pushes the ring down strongly against the bottom of the ring groove and out against the cylinder creating a very effective seal.

This initial light sealing action, sometimes in combination with a downward scraping profile of the ring, also helps scrape a small amount of oil off the cylinder wall, ensuring good oil control.

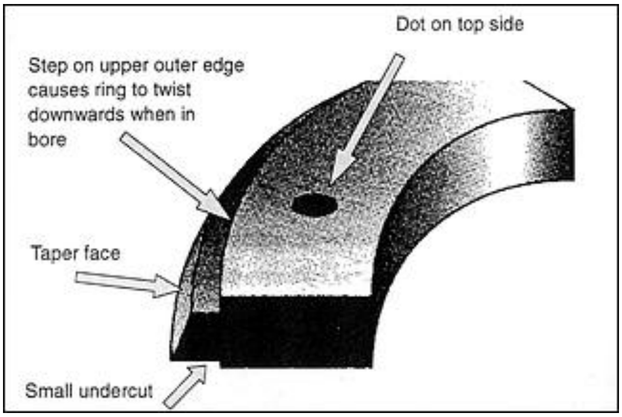
Compression rings are manufactured with a free gap so that when they are compressed into the cylinder they push outwards to create this critical initial light seal. In the installed condition, compression rings must be circular to match the cylinder. They can be designed to have a uniform contact pressure against the cylinder around the entire circumference of the ring, or have higher or lower pressure at the gaps.

Low tip pressure rings are often used in two stroke engines where the rings are free to rotate. This reduces the possibility of the gaps of the ring protruding into the cylinder ports and being broken off as the piston moves up and down. High tip pressure rings are designed to create extra damping (or friction) at the ring gap to raise the speed at which ring lifting or flutter occurs (ring flutter is associated excessive amounts of blowby).

However, increased wear occurs at the areas of higher pressure while the areas of lower pressure (at the two and ten o'clock position) can allow leakage to occur, especially in distorted cylinders or if the radial depth of the ring is high, making it too stiff to conform.

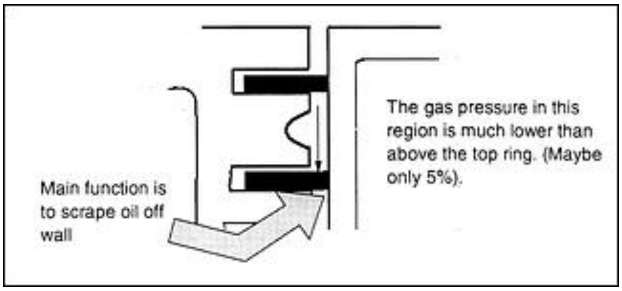
Complex mathematics are required to calculate the special non-round cam shapes that a compression ring requires in the free state, in order that it obtain these various ideal pressure patterns. This special cam shape is machined into compression rings early in the manufacturing process. Factors such as material variations, casting and machining residual stresses and radial depth variations need to be controlled in the manufacture of compression rings to minimise variations from the mathematical ideal.

2. Second Rings



Second rings are primarily there to assist the oil ring to prevent upward movement of oil. The reverse torsional twist ring is especially effective because it twists downwards in its groove. As a result, its lower edge seals against the bottom outer corner of the second ring groove and this prevents oil from bypassing the ring on the downward stroke of the piston. On the upward stroke, the high taper angle allows oil to pass by the ring rather than be scraped upwards.

Second rings must be fitted in the groove the correct way. Most second rings have a "dot" to signify the upper side though in some instances the manufacturer's name is stamped on the upper side.



Regular grey iron is almost always used in second grooves. Where it differs from SG is that it has the ability to run against a bore uncoated and it is very scuff resistant. It is not as hard as SG. It beds in very quickly. Naturally it is not as strong as SG iron but in a second groove the strength requirement is not the same as in a top groove.

What if no second rings are used? It is possible to delete the second rings in a performance application. Doing this, in conjunction with a file back top ring (with a fairly small gap) can reduce friction, and it can also allow the piston to be shorter in the ring belt region with consequent weight savings. However if oil consumption is to be kept under control the oil ring needs to have more load, and this negates friction benefits. However blowby can be less with only one compression ring. Formula One engines have only one compression ring.

Ring Gaps

One minor avenue remains for gas escape is the area bounded by the gap end clearance, which is necessary to prevent ring ends butting at operating temperature.

End clearance on piston rings is controlled within 0.07 to 0.12mm per 25mm of bore size, being of lower value than this under engine operating conditions - hence there is only a very small area for gas to pass.

Piston ring manufacturers supply rings, whether for original equipment or aftermarket, pre-gapped. The diameter to which pre-gapping is carried out will be nominal bore diameter, whereas in practice bore sizes may vary according to the grade - some engine manufacturers have as many as 15 grades, covering 0.1mm increments though the tendency is for less. It is, therefore, conceivable for piston rings as supplied to have more gap than the ring manufacturers' specification. In most cases this increase in gap does not matter.

It must be remembered that there are two compression rings and in any case the combustion process takes place in milliseconds and there is simply not time for significant leakage to occur. During operation of an engine, blowby passing through the ring gap is under very high pressure and it reaches what is termed "sonic velocity". At this point any increase will not result in any increase in gas velocity (hence the rate of escape of the gases). From this point of view, leak-down tests are of little or no value in determining engine condition, as they measure leakage under static and low pressure conditions.

Gap Types

Most gaps are straight cut, however, there are applications requiring different gap types.

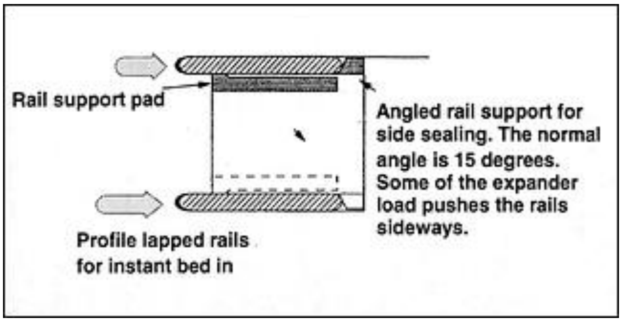
Oil ring gaps are of even less significance. While production rings may have gaps specified at 1.00mm nominal, up to 1.75mm would be satisfactory in most cases, again keeping in mind the labyrinth effect with gaps spaced apart.

The gas which does escape the piston rings, and which is returned to the intake charge, is termed blowby. The control of blowby to an acceptable level is important because excessive blowby means loss of engine power, leads to ring sticking and an increase in emissions. That is why manufacturers tightly control piston ring shape and flatness, two factors important for good gas sealing. Blowby is measured under laboratory conditions by sealing off the engine's crankcase and attaching an accurate gas meter by means to the breather on the oil filler cap. A typical 2-litre engine can expected to have a blowby figure of 20-30 litres per minute **under full load conditions**.

So that the upward passage of oil around and behind the compression rings is controlled, compression rings must have proper seating on the lower faces of the piston ring grooves, just as proper seating is necessary for the control of blowby. The control of oil past the ring faces relies on the ring face attitude to the cylinder wall and the quick seating or bedding-in of the ring face. Bedding-in or mating of the rings with the cylinders is the initial wear of both rubbing surfaces necessary to render them compatible during operation and consistent with the establishment of an oil and gas seal.

The attitude of the ring face to the cylinder wall must at all times be "downward scraping" to carry the excess oil on the cylinder walls downwards ahead of it. For this reason, the top edge of the compression ring must never be the only portion of the ring face to be touching the bore - if it were, it would have an upward scraping effect and would cause a very high rate of oil consumption.

3. Oil Control Rings



In engine lubricating systems much more oil is thrown onto the cylinder walls than is necessary for piston and ring lubrication. To prevent excessive oil consumption (and a smoky exhaust!) each piston is supplied with one or two oil control rings which are placed in piston grooves below those for compression rings.

The prime function of the oil control ring is to scrape excess quantities of oil from the cylinder walls and to return it to the crankcase through draining areas, and, secondly, to meter sufficient oil to satisfactorily lubricate the compression rings.

Requirements by engine manufacturers for lower oil consumption led to the introduction of segmental oil rings. There are two basic types of segmental oil rings; both types have two steel rails for scraping oil from the cylinder walls, however, one type uses a wave form shaped expander and a cast iron or pressed steel spacer, while the other has a circumferential abutment spacer-expander to provide outward force on the steel rails. By far the most common is the three piece circumferential type.

Conformability to "out-of-round" cylinder bores of both types of segmental oil rings is excellent and they also have the ability of sealing the rails against the groove side faces. This is effected by the design of the circumferential expander which has a large number of angled tabs protruding for rail support. When the assembly is compressed into a bore, a portion of the load applied by the expander is imparted to the steel rails in the direction of the side faces.

Segmental oil rings have a degree of independent rail action, which means both rails contact the bore even when the bore shows some degree of wear or taper, or with short skirt pistons with higher piston-to-bore attitude angles. Oil control is therefore maintained. The steel rails are chromium plated for compatibility with cylinder walls (since the carbon steel would quickly scuff if not coated) and for wear resistance. The scraping edge is designed to have a high contact pressure for quick "bed-in" on both newly honed and worn cylinder surfaces.

Less popular and less effective - but still in use - is the unitised oil ring. This has two rails, a sine wave expander and a spacer. Its load is derived from compression of the sine wave expander against the back of the oil ring groove and therefore relies upon the accuracy of machining of the piston groove for correct wall pressure.

Wall Pressure (or oil ring load)

While the compression rings derive most of their wall pressure from the combustion gas pressure, oil rings must generate their own wall pressure. The expander can be thought of simply as a compression spring. It is longer in length when in the free state than when compressed into the bore and it is the difference in these two lengths that determines the load (and hence wall pressure) for a given expander.

A typical amount of compression is 4mm for an 80mm bore, but this can vary according to the spring rate of the expander. A stiff expander has a high spring rate and deflects less on entry to the bore, but will lose load more rapidly as wear takes place.

A low spring rate expander will show less load drop off with wear, but has greater deflection. If the deflection is too great, assembly of the rails may be difficult since the rails may protrude over the edge of the ring load during assembly. This is known as popout, or necklacing.

Typical wall pressures for new engines in the 80-100mm bore size may be 1 MPa, but some aftermarket manufacturers make assemblies with wall pressures as high as 2MPa. This may control oil better initially, but leads to rapid wear and greater friction losses.

Expander Types (Circumferential)

There are numerous types of circumferential expanders in common usage. In general terms equivalent performance may be obtained from carbon steel and stainless steel types and within both there are numerous shapes and types. Once installed, the important factors are wall pressure and conformability, the latter a function of the rail radial depth.

There is a trend towards the lowering of loads and a reduction in radial depth in the interest of reduced engine friction. Reduced radial depth allows greater conformability to an out-of-round or distorted bore and as a consequence, the compressive load exerted by the expander does not have to be as high in order to give sealing around the rings outer periphery.

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