**Piston Rings**

**Functions**
One of the more critical components to engine durability and performance are the pistons rings. Piston rings perform the following functions:

1. Form a gas tight seal between the piston and the cylinder.
2. Assist in cooling the piston by transferring heat to the cylinder wall.
3. Apply a film of lubrication oil on the cylinder wall of the engine. The film must provide adequate lubrication properties yet not be excessive which will cause high oil consumption and excessive emissions.
4. Provide a compatible wear surface for the cylinder walls.

The rings must perform these jobs under extreme temperatures, pressures and operating conditions for the life of the engine. In fact, one of the primary determinants of engine durability is the ability of the ring to do the above jobs efficiently.

**Exhaust gas Recirculation (EGR) Engines & Ring Longevity**
Refinements to ring design, cylinder bore finishing techniques and engine oils have helped produce engines that can easily operate more million miles in large heavy-duty diesel trucks before rings wearing out and needing replacement. Ring design and the performance of engine oil is even more critical in exhaust gas recirculation (EGR) equipped engines. Higher cylinder temperatures and pressures combined with reintroduction of soot and corrosive exhaust gases found in EGR engines can affect ring longevity. Some observers have predicted that EGR engines will not have the service life of non-EGR engines.
Rings must also minimize power robbing blow-by which also leads to oil contamination and crankcase emissions.

Adjacent picture of intake manifold of diesel EGR equipped engine. Notice the soot in the intake which is reintroduced into the cylinders. (Q: Where did the soot originate from in the first place?)

**Piston Ring Types**

The quantity, position and composition of rings can depend on a variety of factors. Slower moving engines for example will typically use more rings to minimize blow-by. Since piston rings can produce up to 40% of the friction in an engine fewer, thinner rings having less static tension are desirable. Thinner and fewer rings however will transfer less heat to the cylinder walls when approximately one third of the heat from the piston is transferred to the cylinder walls through the rings. This means pistons will operate at higher temperatures. Thinner rings may also provide improved fuel economy but can handle less cylinder bore distortion leading to more blow-by.

The types of piston ring found in most engines are of three kinds:
- Compression
- Intermediate
  (A combination of compression & oil Control)
- Oil Control
Compression Rings
Compression rings are the rings located nearest the piston crown. They are occasionally referred to as fire rings since they are directly exposed to combustion. Their primary job is to prevent gases from leaking by the piston during compression and power stroke. Gas leakage past these rings, which is power robbing, is referred to as blow-by.

Ring Sealing- Static Tension
Compression rings perform this sealing function a number of ways. One way is through the static force of ring tension against the cylinder wall. Since rings are manufactured, having a larger relaxed diameter than the diameter of the cylinder they are to be installed in, sealing is accomplished by the rings “spring tension” expanding out against the cylinder wall. In older rings designs this force may be easily over 20 lbs of force.

However, in effort to minimize friction losses in an engine, high ring tension is not a desirable feature of a ring in order to seal. A thinner ring with better “knife edge sealing” is preferred. Today, ring tension in gasoline engines may be as low as 4 - 8 lbs of ring force. Low-tension rings can significantly increase fuel economy by decreasing internal friction.

Gas Pressure & Sealing
Another way compression rings seal is enhanced is to use the gas pressure of compression and power stroke to “push” the ring out harder against the cylinder wall when required. For this reason, the thickness of the ring is slightly less than the height of the ring groove. With this configuration, gas pressure gets behind the ring, pushes it out.
against the cylinder wall harder, and pushes down on the ring against the groove for better sealing. This means that higher the cylinder pressures produce better sealing of the combustion chamber.

**Above: Blow-by is power robbing and leads to oil contamination (soot loading, acid formation etc..) Rings need to minimize blow-by.**

During power stroke then, the ring seals more effectively. This is why most blow-by occurs during compression stroke. In gasoline engines, the result is a high hydrocarbon content of crankcase vapours that are recovered through the PCV system and re-burned. In diesel engines, only air is present in the cylinders during compression stroke. Until recently, diesel engine crankcase vapours were simply vented to the atmosphere through a road draft tube. However, oil vapour and droplets produced from piston cooling and throw-off from bearings will be carried out of the engine with blow-by. New environmental legislation for 2007 will have all diesel crankcases closed which means oil and air are separated before air is vented to the atmosphere.

**Crankcase ventilation system on '07 ISX Note inlet from valve cover, outlet to atmosphere and oil line directing coalesced oil back to crankcase. This system also has a pressure sensor.**
Piston speed and size is often a factor in determining how many compression rings are used. Slower speed engines require more rings to minimize the loss of compression pressure. Additionally, since the compression rings are split for installation and to accommodate thermal expansion of the ring, gases can escape through the ring end gap. Two rings rather than one may be used, both having a sealing function.

**Piston Ring End Gap**

Piston ring end gap is necessary to allow for thermal expansion of piston rings. A minimum ring end gap is critical to prevent loss of compression and excessive engine blow-by. Too little ring gap will cause the ends to butt and prevent expansion. Excessive gap will obviously cause a loss of compression and excessive blow-by. A generally specification for ring end gap is .003”-.004” per inch of cylinder bore.

One of the primary reasons for ring breakage in worn engines is the flexing of the ring as it moves from a narrow diameter to a larger diameter. For every 0.001” of cylinder taper, the ring end gap will expand 0.003”. This flexing will eventually fatigue the ring and cause it to break. For this reason, the maximum amount of cylinder taper is 0.001” per inch of bore. No more than 0.004” of taper is generally allowed in most cylinders. To measure this taper, a dial bore gauge is generally used. An alternative method is to measure the ring end gap with the ring at several locations in the cylinder, near the top, middle, and bottom.

**Checking ring end gap is critical to prevent blow-by, compression loss and buckling of ring**

Measuring piston ring gap with a feeler gauge after installing the rings into the cylinder and squaring them up with a piston inserted upside down.
Method 3. Feeler Gauge

Tools required:
1. One feeler gauge set
2. One new or used piston compression ring

Install the piston ring into the cylinder sleeve squarely at the top of the piston ring travel area and measure the piston ring end gap with the feeler gauge. Record the reading.

Next install the same piston ring into the cylinder sleeve below the piston ring travel area at the lower end of the cylinder sleeve. Record the measurement.

Using the feeler gauge method, for every .003" increase in piston ring end gap there is a corresponding .001" increase in cylinder sleeve bore. In other words, as much as .012" end gap difference in the two readings is possible with taper still within the max. spec. of .004".

Cylinder Sleeve Inspection
Clean thoroughly with brush before reuse.
Compression Ring Shape & Materials

Iron Alloys
Cast iron rings were used for ring material in early automotive days. The ability of iron to break-in easily, to conform to cylinder irregularities and resistance to high heat made it an ideal material. Cast iron however is brittle. A ring that is made out of grey cast iron when bent too far will snap. The material has little flexibility because of its sharp rectangular granular microstructure. This means it will easily fracture if the metal is shock loaded or bent too far. Oil control rings are still commonly made from this material so it is important to use a ring expander when installing these rings on a piston. Today, cast iron compression rings may only ever be used rarely during rebuilding of gasoline engines.

Ductile Iron
Turbocharged diesel engines with high heat and cylinder pressures plus requirements for durability require better materials. Ductile or malleable iron is used as the ring base material since it does not easily fracture. Intermediate rings are commonly made from this material. Ductile iron has been used for years for heavy-duty diesel rings because ductile iron approximately twice as strong as grey cast iron. Ductile iron is also called "nodular" iron because its microstructure contains rounded or nodular shaped grains. This property increases ring strength and permits the metal to bend without breaking. Consequently, ductile iron compression rings can take a lot more pounding than grey cast iron rings without breaking. In fact, a ductile iron ring can be bent like a pretzel without breaking. The disadvantage of ductile iron is it is expensive and is difficult to machine. Furthermore, ductile iron alone is not compatible with cast iron cylinder walls and sill scuff unless coated with chrome or other face materials.

Steel Rings
A much better material for compression rings than cast iron and ductile iron is steel. This material is twice as strong as ductile iron. Since steel is the best material for withstanding the pressure and temperature loads found inside high compression turbocharged diesels, this material has been used for thirty years or more in many heavy-duty diesel applications.
Generally, steel compression rings have the following advantages:

- Better breakage resistance.
- Improved heat resistance.
- Better mechanical stress resistance.
- Reduced ring side wear.
- Reduced groove side wear.
- Longer service life
- Less expensive and complex to manufacture (Made from coiled wire)
**Comparison Piston Ring Alloys**

<table>
<thead>
<tr>
<th>Material</th>
<th>Hardness</th>
<th>Tensile Strength</th>
<th>Fatigue Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey cast iron 22-23 HRC</td>
<td>22-23 HRC</td>
<td>45,000 psi</td>
<td>30,500-psi</td>
</tr>
<tr>
<td>Ductile iron 38-40 HRC</td>
<td>38-40 HRC</td>
<td>180,000 psi</td>
<td>87,300-psi</td>
</tr>
<tr>
<td>Steel (SAE9254) 44-53 HRC</td>
<td>44-53 HRC</td>
<td>240,000 psi</td>
<td>138,600-psi</td>
</tr>
</tbody>
</table>

**Ring Facing Materials**

Chrome plating is used on the ring face to improve wear and heat resistance. This material was used beginning in the Second World war to prevent engines in desert tanks from dusting out due to desert sand ingestion. Chrome however, has one disadvantage; it will cause higher cylinder wall wear in the ring turn-around area since there is very little upper cylinder wall lubricant at this top most point of ring travel. During the 1970’s ring manufacturers found a coating of molybdenum on the ring improves wear characteristics. Wear resistance is improved because “moly” faced rings have a porous finish. This porosity permits oil retention on the ring face which reduces upper cylinder wall wear. A combination of chrome and molybdenum is generally used today for compression rings. One disadvantage of “moly” rings however is the porous ring transfers less heat to the cylinder walls for piston cooling.

**Nitrided Rings**

To obtain the highest possible ring life, newer techniques and materials are now also used. While chrome-moly ring facing material is the choice for most rings today, gas-nitrided rings may eventually displace these rings. Gas nitriding, not be confused with the black phosphate coating that is currently used on many cylinder components to prevent rust during storage, is a hardening process which impregnates the surface of the steel rings with nitrogen. The hardening extends into the ring to a depth of about .001 inches. This hardening technique is almost 50% greater than steel rings and four times that of grey cast iron rings. This improves the ring resistance to.
side wear and face wear to the point where ring wear is negligible. Cylinder walls will wear out before these rings do.

One other exotic diesel engine ring material uses a combination of plasma-moly and ceramics (such as chromium carbide). Ceramics are extremely hard and wear resistant, but do not conduct heat well. Volvo currently is using a "Moly Cermet" (80% moly/20% chromium carbide ceramic) faced ring in a turbocharged heavy-duty truck engine.

Above: Note porous moly-coated ring face on left. The pores are used to retain oil. Also notice the witness line caused by lapping the ring during manufacturing or the normal barrel face wear on a compression ring.

Compression Ring Shape

Keystone shaped rings are the ring shape of choice for most engine manufacturers. Rectangular shaped rings were once the standard ring shape but they have a problem with sticking when combustion and baked oil/fuel residues gum up the groove. Keystone shaped ring action helps keep the ring land clean and prevent ring sticking.

In order to obtain good sealing characteristics and minimize friction a barrel face is often ground on the face of compression rings. The barrel face forms line contact with the cylinder wall to form a tight and relatively friction free contact. The manufacturer prior to packaging laps rings in a cylinder identical to the one that the rings will run in. A “witness line” shows the contact with the cylinder. This same line will grow wider as the ring wears and can be used as a determination of the amount of ring wear.
Intermediate Rings

Intermediate rings may also be termed compression rings. However, intermediate rings perform more than a compression sealing function for gases that may have escaped past the top rings. Intermediate also assist in oil control. Without a small-metered amount of oil on the cylinder walls for the piston and ring lubrication, excessive premature wear will take place. But any excess quantity of oil will lead to high oil consumption and emissions. A taper face is the shape of choice for the intermediate ring allows the ring to perform two functions.

First, the shape can permit the ring to glide over the oil film on the piston up-stroke enhancing the sealing effect of oil between the ring and cylinder wall. On the down stroke the ring will scrape oil from the cylinder back into the crankcase much like a squeegee. A negative or positive direction of twist to the ring will enhance either compression sealing or oil control.

A machined groove in the bottom or top inside edge permits the ring to twist in the groove. Using a ring with a machined groove causes combustion chamber gas pressure to twist the ring.

It is important to note that rings have directional marking to guide the technician during ring installation. Markings usually located on the top of the ring orientate the ring to the top of the piston. For the intermediate ring, direction of orientation is critical since it can lead to high oil consumption, excessive blow-by and low compression if improperly installed.
Oil Control Rings

The last ring type found on a ring pack is the oil control ring. This ring is usually cast iron with scraper rails that remove excess oil from the cylinder wall while leaving a metered quantity. This oil film thickness is no more than typically four millionth of an inch thick.

In three-piece oil rings, there are two narrow side rails and an expander that wraps around the piston. The oil control ring is usually a low-tension type ring and has no gas pressure acting on it in a significant way. For this reason, a metal expander is placed behind the ring to maintain a constant uniform pressure against the scraper rails. The expander exerts both a sideways and outward pressure on the side rails so they will seal tightly against the cylinder walls. The expander ring may be corrugated, slotted or a wire coil.

Like the intermediate and compression rings the oil control ring is vulnerable to premature wear from dirt ingestion into the engine. Scraper rails will show premature wear if abnormal amounts of dirt contaminate the oil through the intake air.
**Ring Installation**

Care must be exercised when installing rings onto a piston and into the cylinder since rings are fragile. Another common cause of ring breakage is overstretching the ring during installation. Ring expanders are tools that stretch a ring just far enough to allow its removal but not too far to cause it to bend or break.

To install a piston into the cylinder and prevent damage to rings the use of a ring compressor is required. A number of designs are available to speed up the installation and ensure trouble-free assembly.

Whenever pistons are removed from an engine, the wear step or ridge should be removed to prevent damage to the rings as well as the piston.

To prevent loss of compression and damage to the cylinder wall ring end gaps must be staggered 120 degrees apart in a three-ring pack configuration. End gaps should *not* be aligned near the wrist pins.

**Tools For Installation of Piston Rings**

![Image of ring compressor and ring expander tools]
When installing piston rings, the end gaps must be staggered at least 120-degrees apart. End gaps should not be located above the pin boss area.

**Cylinder Bore Refinishing**

Cross hatch or fine lines left on a cylinder wall produced by honing is critical for oil retention and ring break-in. The microscopic peaks of the ridges on cylinder walls and rings are worn down during break-in to produce a good seal between the ring and cylinder wall.

Plateau finishing is the choice for bore finish using today’s chrome-moly faced rings. A plateau bore finish is what all types of rings eventually produce when they are fully seated. Plateau finishing reduces the break-in period and reduces oil consumption. Furthermore, the closer the cylinder bore can be finished to a plateau-like condition, the less the rings and cylinders will wear as the engine breaks in. When piston rings seal better from the start, and the longer they will last.

For moly rings a two-step honing process is recommended. A hone with a #280 grit silicon carbide vitrified abrasive should be used first then finish by briefly brushing the bores with a #400 grit stone. No more than 15 strokes should be necessary to produce a high quality finish. The peaks of the microscopic ridges are smoothened or plateaued by finishing the honing with several strokes with an abrasive nylon honing tool or brush.

If a parent bore block (non-sleeved engine) is being honed it is important to minimize bore distortion produced after cylinder heads are installed. The stretching forces in the head bolts can cause distortion of the cylinder bore causing poor ring to cylinder wall sealing. Torque plates are often used to simulate the bore distortion that occurs when the cylinder heads are installed on the block. Honing the block with torque plates installed results in rounder holes and better ring sealing.

**Engines require honing to leave a crosshatch to permit a better fit and sealing between the rings and cylinder wall after break-in period.**

*No piston ring can provide a perfect seal between the piston and the cylinder wall*
Above left – cylinder wall finish without plateau honing Right – after plateau honing. Engines have after break-in like finishes with plateau honing.

Above: Ball and flat stone hones. Ball stones are for deglazing only.

Nylon brushes used to plateau hone cylinders
**Break-in after Rebuild**

It is important that a load be applied to an engine as soon as possible after rebuilding. This permits the gas pressure to force the rings outward against the cylinder walls causing the rings to seat. Without this, the tiny valleys between the microscopic cylinder wall ridges will fill with baked on lubrication oil. Reciprocating movement of the piston will smooth this baked oil into a glazed finish on the cylinder wall. Glazing produces a mirror like finish on the cylinder walls. Thus, the cylinder wall cannot retain oil for lubrication of sealing of the rings leading to low compression, hard starting, low-power, excessive blow-by and high oil consumption.

**Ring & Cylinder Wall Wear**

The constant up and down scraping of the rings against the cylinder walls eventually wears both the rings and bore surface. Cylinders wall wear most at the top since ring pressure and combustion temperatures are the highest. Very little lubrication is also available at the top of the cylinder especially in the ring turn around area. Consequently, taper like wear occurs in the cylinder that decreases compression and increases blowby and oil consumption. Taper also causes the rings to flex in and out as the piston moves up and down, further increasing ring wear and the risk of ring failure. Excessive taper will result in broken rings caused by ring material fatigue.

Rings also fall victim to dirt. Unfiltered air entering the engine carries with it microscopic particles that are abrasive to the rings and bearings. Over time, this can greatly accelerate ring and bearing wear. For this reason, the air induction inspection and air filter service should be carefully performed.

Typical symptoms of worn rings include low power or compression, excessive oil consumption, excessive emissions, high soot loading of engine oil and hard starting. Excessive blow-by into the crankcase will also shorten oil life by dumping a lot of moisture, soot and fuel into the oil. This will form acids and sludge that can further damage the engine.
**Inspection of Rings**
Rings can be inspected for wear by visually or chemically examining the face. Worn rings will show a large wide witness ring. In some instances, ring facing material will flake or be completely removed. When the ring face material is worn away only iron and steel is exposed. Specialized chemical treatment of the ring will cause the ring to change colour depending on whether the face has chrome or iron exposed.

**Evaluating Rings**
While rings may be visually or chemically evaluated after the engine is disassembled, other techniques are available to the technician to evaluate the seal between the piston rings and cylinder wall. The following are common techniques which can be used.

**Compression Testing**
Maximum compression pressure is measured with a pressure gauge installed in the injector or glow-plug hole. When the engine is cranked over maximum pressure values are observed for each cylinder and compared against manufacturer’s specifications as well as for cylinder to cylinder variations. Values should not vary between cylinders of more than 10%.

- Two adjacent cylinders with low compression may indicate a blown head gasket. If cylinder pressures are all consistently low, a small quantity of oil can be squirted into the cylinder.

- If the pressure increases to normal values, worn rings and cylinder walls are indicated. This effect is due to the enhanced sealing caused by the oil film. If pressures do not rise after a second test with additional oil in the cylinders, some other defect is present such as a leaking valve or perforated piston.

Compression testing is rarely used on diesel engines due to the negligible clearance volume of the cylinders and the prospect of hydraulic locking the cylinders with oil. Wide variations of compression results are possible due to piston design in a diesel.

**Leak Down Testing**
This test can be performed separately or in conjunction with compression testing and is more practical for diesel engines. Unlike compression testing, air is fed into a cylinder at pressures between 80 and 120psi. The engine should be warm to minimize clearances between the cylinder walls and piston. With the piston positioned at TDC and the engine held in position the leak tester connected to the cylinder a second gauge on the tester will record the percentage of air leaking into the cylinder.

- An engine in good condition should generally show only 5 to 10% leakage. Some engines in acceptable condition may indicate as high as a 20% leakage. But more than 30% leakage indicates problems.
- A cylinder that has poor compression but minimal leakage may indicate a valve-train problem such as a worn cam lobe, broken valve spring, inadequate valve lift due to a defective cam follower or even a bent push rod.
• If all the cylinders have low compression but show minimal leakage, the most likely cause is incorrect valve timing. A slipped notch on a timing belt, timing chain or incorrectly installed cam gear may be the problem in this instance.
• If compression is good and leakage is minimal, but a cylinder is misfiring or shows up weak in a power balance test, may indicates a defective injector or injection pump on a diesel engine.

Crankcase Pressure testing (Blow-by Test)
One of the best recommended practices for evaluating the condition of piston rings is a crankcase pressure test. Since blow-by in the crankcase is primarily determined by the condition of the rings, the quantity of blow-by and crankcase pressure is indicative of ring condition. Crankcase blow-by pressure is usually very low- just a few inches of water column pressure when the engine is under full load (rings seated). When the rings and cylinder walls are worn, blow-by volume increases which drives up crankcase pressure. Blow-by is measured by installing a restriction orifice on the crankcase road draft tube. The warmed-up engine is then operated at full throttle to measure the pressure. Generally small to mid bore engines will be allowed a maximum of 10” of H20 pressure while larger engines as much as 18” of water column.
Tools used to measure crankcase blow-by.

High crankcase pressure may also be caused by leaking turbochargers seals, intake manifold leaks and worn valve guides.
**Oil Consumption & Rings**

Worn rings can lead to high oil consumption. Excessively worn ring grooves can also lead to oil consumption. The adjacent diagram from John Deere demonstrates how worn grooves leads to high oil consumption. Measuring side clearance of rings is another important determination for the reusability of pistons. Ring grooves can also be evaluated using OEM specific ring groove gauge pins.
Before removing rings, the cylinder ridge must be removed to avoid damaging the rings and piston.
PISTONS AND RINGS

Dusted Engine

A dusted engine has premature, severe wear on all ring wear surfaces, caused by ingested airborne dirt.

On oil control rings, the degree of wear can be determined by the width of the rails. The ring on the left in Figure 77 shows normal wear, while the ring on the right shows extreme wear. The rails on the right ring are worn completely away.

The compression rings also show extreme wear, as evidenced by wear at the ring ends versus the ring body. Refer to Figure 78.

Airborne dirt promotes top (compression) ring face and side wear, but affects oil control rings by wearing the face rails (widths of rails increase).

Wear step in sleeve as a “rule of thumb”: Normal wear is less than 0.001 inch per 100,000 miles.

Figure 75 — Dusted Engine
Figure 76 — Sleeve Wear
Figure 77 — Oil Ring Wear
...continued
Rings stuck from excessive cold idle