CYLINDER BORES
& PISTON RINGS Guide

The proliferation of engines and the variety of bore and stroke combinations on the strip as well as the street has resulted in a variety of changes to piston rings. Some of the influences suppliers point to when discussing the newest generation of rings include the following:

Engines: From the rise of the small performance four-cylinder to the reemergence of the Chrysler Hemi to the continued dominance of the GM LS-series of engines, number of cylinders doesn't seem to matter. There's more than enough power available under every hood.

Ring designs: Racers want thinner rings that generate less tension to reduce friction, so ring dimensions have been shrinking. Many NASCAR and Pro Stock engines are now using compression rings as thin as 0.7 mm, and most Formula One engines are now down to 0.6 mm. These skinny rings produce very little tangential load (about 1.5 pounds), which minimizes friction and allows the rings to conform more easily to any bore distortion. Many of these engines are also using Napier style second rings to keep oil out of the combustion chamber (where it can cause detonation).

Ring materials: Cast iron piston rings remain popular with many budget-minded dirt track claimer motors as well as many street performance and other racing applications. But for higher output engines, ductile iron or steel rings are usually required. Ductile iron rings have roughly twice the tensile strength of gray cast iron, and three times the fatigue strength. Steel rings, by comparison, have almost four times the tensile strength and fatigue strength of gray cast iron. Increased strength reduces the risk of ring breakage and failure. But the trade-off is a higher price.

For high-boost turbocharged and supercharged engines, and engines using large doses of nitrous oxide to add horsepower, ductile iron or steel top rings are probably a must. Many racers prefer to use nitrided rings made from steel wire because the rings can handle high loads and thermal shock better than other materials. Nitriding penetrates into the metal and won't flake off like other surface coatings.

Plain cast iron rings are not recommended for engines that run on alcohol because alcohol cuts lubricity. Some type of coated rings or chrome rings must be used with alcohol.

On engines that have coated cylinder bores or liners, moly or tungsten carbide faced rings work well.

Replacement rings come in various types, styles and sizes. Standard size rings are okay if the cylinders are not worn excessively (which requires measuring taper with a cylinder bore gauge). But oversized rings are obviously required if the cylinders are worn and are bored to oversize.

Ring size will also depend on the pistons used (shallow groove or deep groove as well as groove height). Most late model engines have "low tension" piston rings that are thinner and narrower to reduce internal friction. Some are as small as 1.0 mm but the most common sizes are 1.2 to 1.5 mm. Rings designed for standard grooves must not be used in shallow groove pistons, nor should narrow rings be used in deep groove pistons.

The ring material as well as the facing (chrome or moly) should match the original application or be a suitable substitute for the original rings. Steel rings are used in many high output, turbocharged and supercharged engines, as well as diesels. Ductile iron rings may also be used, as these are also stronger than plain cast iron rings. Cast iron rings are still a popular choice for many older engines as well as "economy" rebuilds, but cast rings cannot provide the durability or longevity of moly or chrome rings.

The top ring is the primary compression control ring because it seals the combustion chamber and takes the brunt of the heat. That's why the top ring on most late model engines is faced with a molybdenum (moly) coating. Many top rings are also steel or ductile iron, and on many Japanese engines the top ring is nitride coated to improve durability. Chrome rings are also used in many Japanese engines.

In addition to sealing combustion, the top ring also helps cool the piston by conducting heat from the piston to the engine block. A decade ago, the land width between the top ring groove and piston crown was typically 7.5 to 8.0 mm.

Today that distance has decreased to only 3.0 to 3.5 mm in some engines. This minimizes the crevice just above the ring that traps fuel vapor and prevents it from being completely burned when the air/fuel mixture is ignited (this lowers emissions). But the top ring's location also means it is exposed to much higher operating temperatures.

The top ring on many engines today run at close to 600° F, while the second ring is seeing temperatures of 300° F or less. Ordinary cast iron compression rings that work great in a stock 350 Chevy V8 can't take this kind of heat. That's why many late model engines have steel or ductile iron top rings. Steel is more durable than plain cast iron or even ductile iron, and is required for high output, high load applications including turbocharged and supercharged engines as well as diesels and performance engines.

Under the top compression ring is the number two ring, which is the second compression ring. The number two ring assists the top ring in sealing combustion, and also helps the oil ring below it with oil control. Most second rings have a tapered face with a negative twist. This creates a sharp edge that scrapes against the cylinder wall for better oil control. Some new second rings designs are now using a "napier" style edge that has more of a squeegee effect as it scrapes along the cylinder wall. This helps reduce friction and oil consumption even more.

The third ring is the oil ring. This is typically a three-piece ring (though some are four-piece, two-piece or even one-piece) that helps spread oil on the cylinder wall for lubrication and scrapes off the excess oil to prevent oil burning. In three-piece oil rings, there are two narrow side rails and an expander that wraps around the piston. The expander exerts both a sideways and outward pressure on the side rails so they will seal tightly against the cylinder walls.

Ring Installation

Rings are sometimes damaged by improper installation. Always use a ring expander to mount the rings on the pistons. This will minimize the risk of breaking or twisting the rings, which can happen if the rings are hand-installed on the pistons. A ring compressor will be needed to install the pistons in the block.

Ring end gaps must be checked to make sure they are within specifications. Check the end gap by placing a ring about an inch down in the cylinder bore and measuring the gap between the ends with a feeler gauge. The gap can be increased if needed by filing the ends of the ring.

To improve ring sealing, some late model engines such as Ford 4.6L and Corvette LS1 are now using a wider end gap on the second ring. The end gap on the second ring is 1.5 to two times that of the top ring. The actual specification may range from .006˝ to .013˝ greater than the top ring depending on the application. The idea here is to treat the rings as a dynamic rather than static assembly.

When the combustion pressure over the top ring is greater than the pressure between the top and second ring, it forces the top ring downward and outward to seal against the piston groove and cylinder. But if pressure builds up between the two rings, it can prevent the top ring from sealing and increase blowby. One way to maintain the pressure differential is to open up the end gap of the second oil ring. A wider end gap provides an escape route for blowby gasses that get past the top ring. This prevents pressure from building up so the top ring will continue to provide maximum sealing.

On some pistons, an "accumulator groove" is machined into the piston between the top and second ring to increase the volume of space between the rings. The accumulator groove helps reduce the buildup of pressure until the blowby gases can escape through the end gap in the second ring.

Blowby is the volume of gases that are entering the crankcase past the piston rings. Contrary to what many people think an engine typically has more blowby at idle than at higher rpms. As the speed goes up, the rings actually seal better and blowby drops.

How much blowby is normal? Dividing an engine's maximum horsepower output by 50 will give you a ballpark number for how much blowby you would normally expect to see. For example, a street performance engine that makes around 500 horsepower will typically have about 10 cfm of blowby with conventional pistons rings and ring end gap tolerances. Higher performance engines that are built to tighter tolerances will usually have less blowby, as might those with gapless piston rings. An 800 to 900 horsepower NASCAR motor, for example, might only have 5 cfm of blowby.

Less blowby means more usable horsepower. Being able to baseline the actual blowby in an engine means you can then go back and try different ring configurations, ring types (conventional or gapless), different ring end gap settings and cylinder wall finishes to see which combination gives the best seal and the least amount of blowby.

Measuring blowby has been one of the best kept secrets with performance engine builders because it allows them to see how well the rings are or are not sealing. It also allows them to detect any ring flutter that may be occurring within a particular rpm range, and to then change the mass or end gaps of the rings to minimize the problem.

For naturally aspirated engines, a top ring end gap of .004″ per inch of bore diameter is often recommended for a stock or moderate performance engine. For a 4.000″ bore, that translates into a top ring end gap of .016″ to .018″. But this will vary depending on the power output of the engine. On performance engines, the gap needs to be increased to accommodate greater thermal expansion due to higher heat loads. An oval track motor might require a top ring end gap of .018″ to .020″, while a turbo or supercharged racing engine might need as much as .024″ to .026″ with a 4.000″ bore.

The recommended end gaps for second compression rings would also the same as the top rings, with slightly larger gaps if you want to minimize pressure buildup between the rings. The recommended ring end gap for most oil rings (except the new super narrow one-piece rings) regardless of engine application is typically .015″.

Gas Ports & Gapless Rings

Another trick to improve ring sealing at high rpm is to run pistons that have gas ports behind the top ring. Combustion pressure blows through the port to help seal the ring from behind and underneath. Gas ports work best at high rpm (above 7,000 rpm) and are not recommended for street engines.

Getting rid of the ring end gap altogether can also improve sealing, cooling and horsepower. Gapless rings eliminate the gap between the ends of the ring by overlapping slightly. Some engine builders who have switched to "gapless" top or 2nd compression rings say they've gained three to five percent more horsepower with no other changes. Gapless rings are said to allow less than 1 cfm of blowby and on alcohol-fueled engines, a gapless top ring or second ring helps keep alcohol out of the crankcase.

Gapless rings made of hybrid iron and different grades of steel are available in most popular sizes. The rings are also offered with various wear-resistant face and side coatings. One such coating that has proven to be extremely durable is a plasma vapor deposited chrome nitride coating. The thin film coating adds hardness and wear resistance that extends both ring and cylinder life, according to one ring supplier who uses this type of coating.

Surface finish specifications have changed dramatically in the last 15 years. New ring and piston technology has shops fitting pistons with no clearance so you had better have a good handle on surface finish parameters and what they mean, along with being able to measure them. Additionally, new coatings for cylinders have changed the way cylinders are machined. Some of the new coatings can only be honed with diamonds.

Gone are the days when you fit a piston into a cylinder bore with clearances from .0025″ to .004″. Today, piston-to-wall clearances are much tighter and in some cases are even “zero-fit,” so you have much less room for error than in the past.

Cylinder bores must also be properly resurfaced (plateau finish is best). For plain cast iron or chrome rings in a stock, street performance or dirt track motor, hone with #220 grit silicon carbide stones (or #280 to #400 diamond stones) to within .0005” of final size. Then finish the bores with a few strokes using an abrasive nylon bristle plateau honing tool, cork stones or a flexible abrasive brush.

For moly faced rings in a street performance, drag or circle track motor, hone with a conventional #280 grit silicon carbide vitrified abrasive, then finish by briefly honing to final size with a #400 grit vitrified stone or #600 grit diamond stone (or higher), plateau honing tool, cork stones or a brush.

For stock and street performance engines with moly rings, an average surface finish of 15 to 20 Ra is typically recommended. for higher classes of racing, you can go a little smoother provided you don’t glaze the cylinders.

For moly or nitrided rings in a performance motor, hone with #320 or #400 vitrified stones, and finish with #600 stones, cork stones, a plateau honing tool or brush. Cylinders must also be cleaned to remove all traces of honing residue, and lubricated with oil before the pistons are installed. The finish and crosshatch in the cylinder bores must match the requirements of the rings that are used. Ring manufacturers typically recommend a crosshatch angle of 22° to 32° as measured from horizontal and uniform in both directions.

Cylinder honing is one of the key components in building any engine, whether it is a street stock budget remanufactured engine or a 900 horsepower all-out performance motor.

The finish on the cylinder walls is critical for proper piston ring lubrication and sealing. The bore geometry is also important, and must be round, cylindrical and straight for optimum sealing and minimum blowby.

The equipment used to hone cylinders has changed in recent years as the demand for better surface finishes, faster cycle times and lower production costs have driven the technology. Many engine builders have replaced their manual honing equipment with programmable automatic honing machines that have load-sensing controls. These machines provide the precision and repeatability to achieve today’s higher quality cylinder bore finishes. When the load-sensor detects a high spot in a cylinder, the controls keep the hone head working in the same location until the high spot is gone. The ability to vary dwell in any part of the cylinder bore results in a rounder, straighter bore with better overall bore geometry.

Some of the newest honing machines with all the bells and whistles even have the capability to cycle the hone head from one cylinder to the next, and then from one bank to the next. Once the operator sets up the equipment and the numbers he wants, the machine does the rest. He doesn’t have to baby-sit the equipment while the machine is honing the block.

Diamonds Are (Almost) Forever

Honing machines have also been upgraded to handle the latest generation of diamond honing stones. Diamond has become the material of choice for both high volume production engine rebuilders (PERs) as well as custom engine builders (CERs) and performance shops. The reason? Diamond honing stones cut faster, last up to 50 times longer and leave a much more consistent bore finish than conventional vitrified abrasives such as silicon carbide and aluminum oxide.

A set of diamond honing stones may cost up to 20 to 30 times as much as a set of conventional honing stones, but when their much greater longevity is factored in, diamonds cost less in the long run – and their consistency is much better regardless of any cost difference. Advantages such as these have won over more and more converts to diamond honing.

Diamond honing makes the most economic sense when an engine builder is working within the same range of bore dimensions on a series of engines. Because of the high initial cost of diamond stones, a custom engine builder who rebuilds anything and everything that comes in the door may not find it economical to buy diamond stones to fit a wide range of bore sizes. But if the majority of honing work he does is on engines with bores in the 4.000˝ range (plus or minus a quarter inch), he can probably cover most of these applications with a single set of diamond stones.

The best estimates say that somewhere between 50 to 60 percent of all the cylinders that are honed today by aftermarket engine builders are being honed with diamond stones. That's a dramatic shift from a decade ago when diamonds where used almost exclusively by the OEM's in their new engine plants and by only the biggest PERs. Nowadays, almost everybody uses diamonds – even many of the die-hard performance engine builders who don't build a lot of engines, but who require the tightest tolerances and highest quality bore finishes for their professional racing customers.

Diamond honing stones are available for most popular honing heads. But to maximize the benefits of diamond honing, the honing machine must be capable of handling higher loads. That means buying new equipment if you are serious about upgrading to diamond.

Diamond is the hardest natural substance known, so it can hold a cutting edge much longer than a conventional abrasive. This means the bond that holds the diamonds can also be harder because it doesn't have to wear away as quickly to expose fresh stones on the surface. The trade-off is that diamond cuts differently than conventional abrasives and requires more pressure. Diamond tends to plow through a metal surface rather than cut through it. This can generate heat and distortion in the cylinder bore if the wrong type of equipment, pressure settings or lubrication is used in the honing process.

Diamond is also good for rough honing cylinders to oversize because it can remove a lot of metal fast. Consequently, you can use a diamond hone in place of a boring bar. But rough honing takes more pressure and requires more horsepower from the honing machine. Because of this, diamond stones work best in equipment that has been designed to take maximum advantage of diamond's cutting properties. That's why honing machines that have been re-engineered for diamond stones typically have more rigid components and more powerful motors. This doesn't mean you can't use diamond stones in an older hone head or an older honing machine. But if your equipment can't handle the higher loads, you may not achieve the same degree of accuracy and repeatability as you could with equipment that has been specifically designed for diamond honing. Nor can you take advantage of the automation features that are available in the newest generation of honing machines.

Bore Finish

Because of the way that diamond cuts metal, it tends to leave more torn and folded debris on the surface of the cylinder bore than a conventional abrasive. Consequently, a final finishing step is often required to remove this material and to leave a plateau finish in the bore.

By shaving the peaks off the bore surface, the bearing area that supports the piston rings is increased without reducing the valley area that is needed to retain oil for proper ring lubrication.

If the bores are not plateau finished with a final honing operation or finishing step, the rings will do the work instead. The scouring action of the rings will wear down the peaks in the bores, but it will also take a toll on the rings, shortening their ultimate service life. The metal that is worn off by the rings will also end up in the crankcase, and can contribute to wear elsewhere inside the engine. That's why many engine builders today favor the plateau honing process as the final step in finishing a cylinder.

A plateau finish can be achieved a variety of ways by using a two or three-step finishing process with conventional or diamond stones, by polishing the cylinders with a cork stone, or by finishing with a plateau honing tool or brush. Stroking the bores with a flexible abrasive brush or a plateau honing tool with abrasive embedded in nylon bristles shears off the sharp peaks and significantly improves the surface finish without changing the bore dimensions.

The proper plateau honing technique can generally get the surface finish down to 8 to 12 microinches (roughness average or Ra), with relative peak height (RPK) numbers in the 5 to 15 range, and relative valley depth (RVK) numbers in the 15 to 30 range. This is well within the ideal range for most ring manufacturers. For stock and street performance engines with moly rings, an average surface finish of 15 to 20 Ra is typically recommended.

Diamond honing stones as well as the honing machines that are designed to use them continue to evolve to meet the honing challenges posed by today's engines. Special abrasives are needed to hone performance engines that have hard liners, high nickel or silicone alloys, or hard electrodeposited oleophilic nickel matrix silicium carbide coating facings. The surface hardness in a nickel/carbide hardened cylinder is about 90 HRc, and the thickness of the coating is only about 0.07 mm (.0025˝ to .003˝) thick. Consequently, you don't want to remove a lot of material when honing the cylinder. The coating retains oil well, so the bores can be honed to a super smooth 4 to 6 microinch finish to minimize friction.

Technology advancements now allow for higher spindle speeds and feed speeds to get the job done faster, say the experts. The other part of that equation is that machines are designed better, with better materials, so they generally outperform older machines quite substantially.

There are a few limitations to your capabilities when using a portable bar, say equipment experts, but they do offer a way to get into the business for less financial investment. But for a little more money you can purchase a complete machine with a stand and an airfloat system. The stand will prove to be an invaluable part of a portable boring bar system, especially when used on newer engines. Experts don't recommended mounting the bar on the deck of a new-style thin-wall engine block because it could cause bore distortion.

One option for some smaller, custom shops may be a multi-purpose boring/milling machine. Multi-purpose machines take up much less space in the shop and, for the price of one piece of equipment, you get virtually two machines. Because smaller shops typically don't do as much volume as larger shops, they tend to focus on precision work rather sheer speed and volume.

For the Production Engine Remanufacturer (PER) and those shops looking for speed and automation, there are several options to choose from. Since engines come in many shapes and sizes you need to know what type of work you do most, whether it's heavy-duty diesel engines with larger bore capacity or small motorcycle or karting engines. If you primarily build smaller automotive engines then a machine capable of boring a large diesel engine may not be the best choice for you.

Many of the automated boring machines have programmable boring cycles and automated centering, which optimizes your workflow. **MEPG**