CYLINDER BORES
& PISTON RINGS

Remember the old days? "Smooth" wasn't an issue. Time was, an engine's cylinders were honed to the correct size and then rings were set and engine fired. The piston rings were expected to perform the final finish operation on a cylinder bore. After the initial break-in period, the rings would have knocked off all the peaks and made a nice smooth path to ride on.

Today, most ring manufacturers and OEMs require a much smoother surface to begin with, and most piston rings come pre-lapped and ready to go. If you compare a freshly honed cylinder bore to a worn out bore, there is quite a difference. A worn cylinder bore will have a mirror-like quality to it because most of the peaks have been worn down and the valleys that retain oil may not be as deep. Plateau finishes virtually mimic the break-in period and eliminate much of the wear and tear on the rings and cylinder surface.

According to leading honing experts, a plateau finish can be achieved easily and accurately using the latest equipment and abrasive technology. Engine builders, perhaps recognizing that old equipment may not allow them to achieve the desired finishes, have consistently ranked cylinder boring and honing equipment as two of the most-desired categories on the shop equipment "wish list" in our annual Machine Shop Market Profile (for the complete report, visit *www.engine-builder.com*).

Bores can also be finished with a few strokes of an abrasive nylon bristle plateau honing tool, cork stones or a flexible abrasive brush of the recommended grit or with the proper abrasive quality – your ring manufacturer can make recommendations.

Bristle style soft hones (plateau honing tools) have monofilament strands that are extrude-molded with a fine abrasive material embedded in the strands. The filaments are mounted in different types of holders for use with portable or automatic honing equipment. Another type of brush uses molded abrasive balls that are mounted on flexible metal shafts so the balls can easily conform to the surface. Brushing helps sweep away torn and folded metal on the surface while removing many of the sharp peaks to make the surface smoother.

When finishing the cylinders with a brush, only light pressure is required. The rpm of the brush should be similar to that which the cylinder was originally honed, and no more than 16 to 18 strokes should be applied (some say 8 to 10 strokes is about right). Too many strokes with a brush may produce too smooth a finish in a cast iron cylinder that won't retain oil. Reversing the direction of rotation while brushing helps to remove the unwanted material on the surface. The end result should be a cylinder that provides immediate ring seal with little if any wear on the cylinder wall or rings when the engine is first started.

With the right plateau honing techniques, you should be able to get the surface down to an average roughness of 8 to 12 Ra or less, with RPK (relative peak height) numbers in the 5 to 15 range, and RVK (relative valley depth) numbers in the 15 to 30 range.

Crosshatch

Crosshatch is also important because the amount, depth and angle of the crosshatch in the cylinder bores determine how much lubrication the rings receive and the rate of ring rotation.

Excessively shallow crosshatch angles can hinder or slow down the necessary ring rotation that allows the rings to dissipate heat. It can also leave too much oil on the cylinder wall allowing the rings to skate over the surface and the engine to use oil. Too steep of a crosshatch angle may not provide enough oil retention and can result in dry starts and premature ring wear. A steep crosshatch angle can also create excessive ring rotation that accelerates ring and piston groove wear.

Ring manufacturers typically recommend a crosshatch angle of 22° to 32° as measured from horizontal and uniform in both directions.

Piston ring manufacturers are intricately involved with surface finish requirements for cylinder bores and the various types of ring materials and coatings that work best. The key is to achieve the right balance of smoothness and oil support.

According to one piston ring expert, cylinder wear virtually stops when the rings are properly seated in the bore. When a thin film of oil supports the rings, they no longer make any contact with the cylinder wall. This assumes, of course, that the rings conform to the cylinder bores and the surface finish is adequate enough.

Superabrasives

No more than a decade ago, superabrasives such as polycrystalline diamond (PCD) and cubic boron nitride (CBN) were considered too exotic and too expensive for the average engine builder to use. Today, PCD and CBN are mainstream and you can hardly afford not to use them.

What makes these materials so indispensable for engine building today? Their superior hardness is a major factor because it provides outstanding tool life that far exceeds conventional abrasives. A set of metal bond PCD diamond honing stones can typically do 50 to 100 times as many cylinder bores as conventional vitrified stones before they're worn out and have to be replaced. A CBN grinding stone for resurfacing flywheels will typically last ten times as long as a conventional stone. CBN pucks in a milling machine will cut 20 to 50 times as many heads as ordinary carbide pucks. Because of this, superabrasives can provide better overall consistency and reduce down time for tooling changes, and even though they cost more initially, typically provide lower operating costs over the long run.

Superabrasives can also handle higher machining and grinding speeds - in fact, they require it! The ability to cut faster means shorter cycle times, improved productivity and profitability. High cutting speeds, though, also require equipment that is designed to operate at higher speeds. Simply switching your tooling from carbide to PCD or CBN may not cut it if your equipment lacks the horsepower or the adjustability to operate at higher spindle speeds.

Rigidity also becomes more important as operating speeds increase. That's why many equipment suppliers have redesigned their equipment in recent years or introduced new resurfacing machines and honing machines that are capable of taking full advantage of the benefits provided by PCD and CBN.

Vitrified abrasives can certainly deliver a high quality finish, but not with the speed and consistency of metal bond diamond honing stones. With conventional abrasives, the stones wear almost as much as the metal surface in the bore as the cylinder is being honed.

Stone life depends on the hardness of the abrasive, the hardness of the substrate that holds the abrasive together, the hardness of the engine block, honing speed, the load on the stones, and the amount of metal that's removed from the cylinder. Consequently, you have to constantly monitor the honing process and compensate for stone wear to keep the bores round and straight. It's a balancing act between cutting action and stone life.

With diamond honing stones, the amount of wear experienced by the stones is almost nil. 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. After honing hundreds of cylinder bores, the stones still look and cut like new. Conventional vitrified honing stones, by comparison, will be completely worn out after 200 to 250 cylinder bores.

Diamond honing stones aren't cheap. They may cost $500 to $700 for a set versus $15 to $35 for a set of conventional honing stones. So initially, changing to diamond requires a significant up front investment. But the payback comes over the long haul because the stones last and last (assuming you don't overstroke a cylinder bore and break them!). Breakage is a risk with any type of honing stone, so it pays to be especially careful when honing with diamond stones.

Diamond Honing

Because diamond is a harder material and wears more slowly than conventional abrasives, it cuts differently and typically requires more pressure. This increases the risk of bore distortion, especially if the wrong honing speed, stroke rate or coolant is used. But many diamond stones today use an improved bond that allows the stones to cut with less pressure than before. This reduces the risk of bore distortion with minimal change in stone life.

If you're switching from conventional stones to diamond, you'll generally have to use a higher number grit to achieve the same Ra (roughness average) when finishing a cylinder. For example, if you have been using #220 grit conventional stones to finish cylinders for chrome rings, the equivalent diamond stones might be a #325 grit. If you have been using #280 grit conventional stones to hone for moly rings, the diamond equivalent might be #550 grit stones. The actual numbers will vary somewhat depending on the brand and grade of the stones.

A set of #325 grit diamond honing stones will typically produce a surface finish in the 20 to 25 Ra range, which is about right for moly-faced rings. A set of #500 grit diamond stones, by comparison, will leave a smoother finish in the 15 to 20 Ra range, which is better for performance applications.

To hone properly, diamond stones really need a honing machine that's been designed for diamonds. Such machines usually have stronger gears, a higher horsepower motor, more rigidity and programmable controls. Diamond honing requires less babysitting so it lends itself much more to automation. For portable honing equipment, though, conventional abrasives are probably a better choice because they require less pressure.

Another difference with diamond is the type of lubricant that's required. Some recommend using a mineral oil or organic oil while others say a synthetic water-based lubricant works best with diamond.

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.

Can you get too smooth? It depends on the application, say experts. Typically the smoothest you can get with cast iron materials is about 3 to 5 microinches Ra. There are some racing applications where teams are getting the cylinders that smooth. The only way to get to that level of smoothness is with diamonds. If you want something with a deeper valley and a low Rpk and deep Rvk, you can produce that same finish with diamond too. It might take a different step process to do it but you can achieve it with diamond.

One application where diamond may not be the best choice for cylinder bore honing is on hard blocks or those with nickel/carbide hardened cylinder liners. The hard ceramic facing inside such a liner is a mixture of nickel and silicon carbide about 0.07 mm (.0025˝ to .003˝) thick. This creates a very hard, wear resistant surface that reduces friction and allows the engine to develop more

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horsepower. The surface has a hardness of about 90 HRc. On this kind of surface, fine-grit CBN honing stones typically cut better and leave a smoother finish than diamond.

The practice of coating cylinders with nickel and silicone carbide (the best known name is Nikasil, which is a registered trademark of Mahle Gesellschaft) got its start in Formula 1 racing, and is now used in many different levels of racing from circle track to drag racing to motorcycles.

The liners are also dimensionally stable and experience less bore distortion than ordinary cylinders, which reduces blowby and leak down (some claim less than 1 percent after extended use). But to seal properly, these liners require two things: moly or tungsten carbide faced rings, and a very smooth bore finish.

The surface of a liner with this coating has microscopic pores that do an excellent job of retaining oil for the rings. Consequently, the bore can be finished to a super smooth finish of 4 to 6 Ra or less to reduce friction even more. Such low numbers would be too smooth for grey cast iron and would likely starve the rings for proper lubrication. Chrome plated bores or liners, by comparison, can also provide good lubrication while reducing friction and wear, but chrome is more vulnerable to dirt scoring and there may be some risk of flaking.

Piston Ring Anatomy

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 that are suitable for light duty, everyday driving. 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. On most late model engines, the number one ring is located very close to the top of the piston. 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 sees 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 end gaps must be checked to make sure they are within specifications. End gap is checked 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.

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 four-inch 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 turbocharged or supercharged racing engine might need as much as .024″ to .026″ with a four-inch bore.

The recommended end gaps for second compression rings would also be the same as the top rings, with slightly larger gaps if you want to minimize

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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 and Gapless

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. Some use vertical gas ports with holes drilled from the top of the piston to the top ring groove just behind the ring. Others use lateral gas ports that are drilled through the bottom side of the top land and extend to the back wall of the ring groove. 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 second 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 cubic feet per minute (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.

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.

Poor machining or installation may result in excessive blowby. You can test blowby using a blowby flow meter. The meter measures airflow, and is attached to either the crankcase vent on a valve cover breather, or the PCV valve fitting. On a V6 or V8 engine, the opening on the opposite valve cover must be temporarily blocked so all the airflow from the crankcase will flow past the meter.

A blowby flow meter can tell you precisely how much blowby is occurring inside the engine. Unlike a cranking compression test or a static leakdown test, a blowby test actually measures the volume of gases that are entering the crankcase past the piston rings. The flow meter allows you to measure blowby from any engine speed, all the way from idle to wide-open throttle.

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. **EMPG**