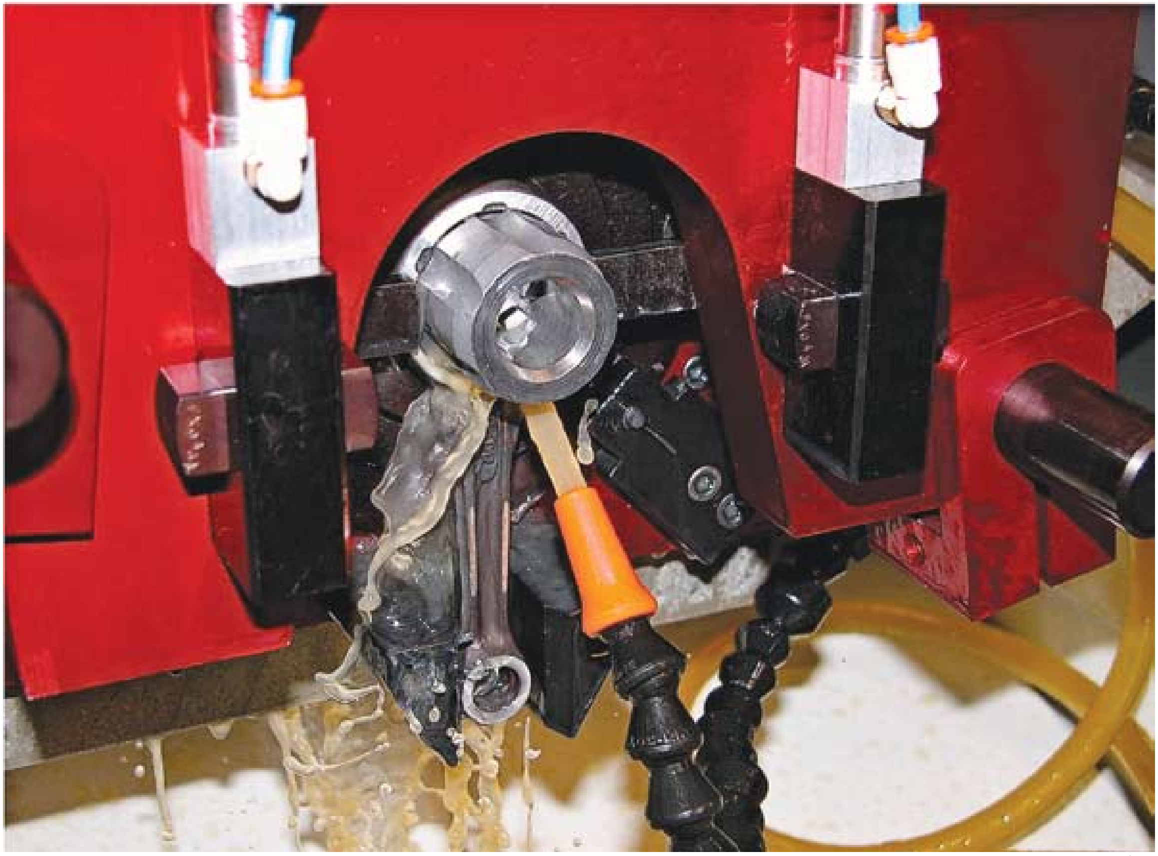


All images: Sunnen Products

A motorcycle connecting rod is honed to a diameter of 1.4173", +0.0001"/-0.0003", with roundness of 0.00008", straightness of 0.00004" and cylindricity of 0.0001".

Small Engines, Big Performance

By Rich Moellenberg, Sunnen Products Co.

Honing of cylinder bores improves sealing and component life to help small internal combustion engines increase power density and reduce exhaust emissions.

A changing federal regulatory climate that targets reduced emissions and noise has led to a convergence of design goals for both small internal combustion engines and automotive engines in the last decade. Today, small-engine OEMs are striving for higher power densities (producing more horsepower and torque from an engine with the same physical size), lower fuel consumption and lower emissions, all while controlling costs.

Engines for outdoor power equipment, ATVs, snowmobiles, motorcycles and outboard motors, along with many piston-type air and refrigeration compressors, share a common operating principle—a piston reciprocates in a cylinder bore. And, like their big brothers on the NASCAR circuit, these engines are also beginning to share a performance-enhancing technology used for racecar and most other auto engines—honing. Honing optimizes the cylinder bore's geometry, surface finish and dimensional accuracy, boosting power density, extending life and lowering emissions.

The fit between the piston and bore, along with the quality of the surface contact between the two, influences power output, combustion efficiency, emissions, component life and vibration. The precision of bore geometry (roundness, straightness, cylindricity and diameter) and surface finish play important roles in engine life and performance.

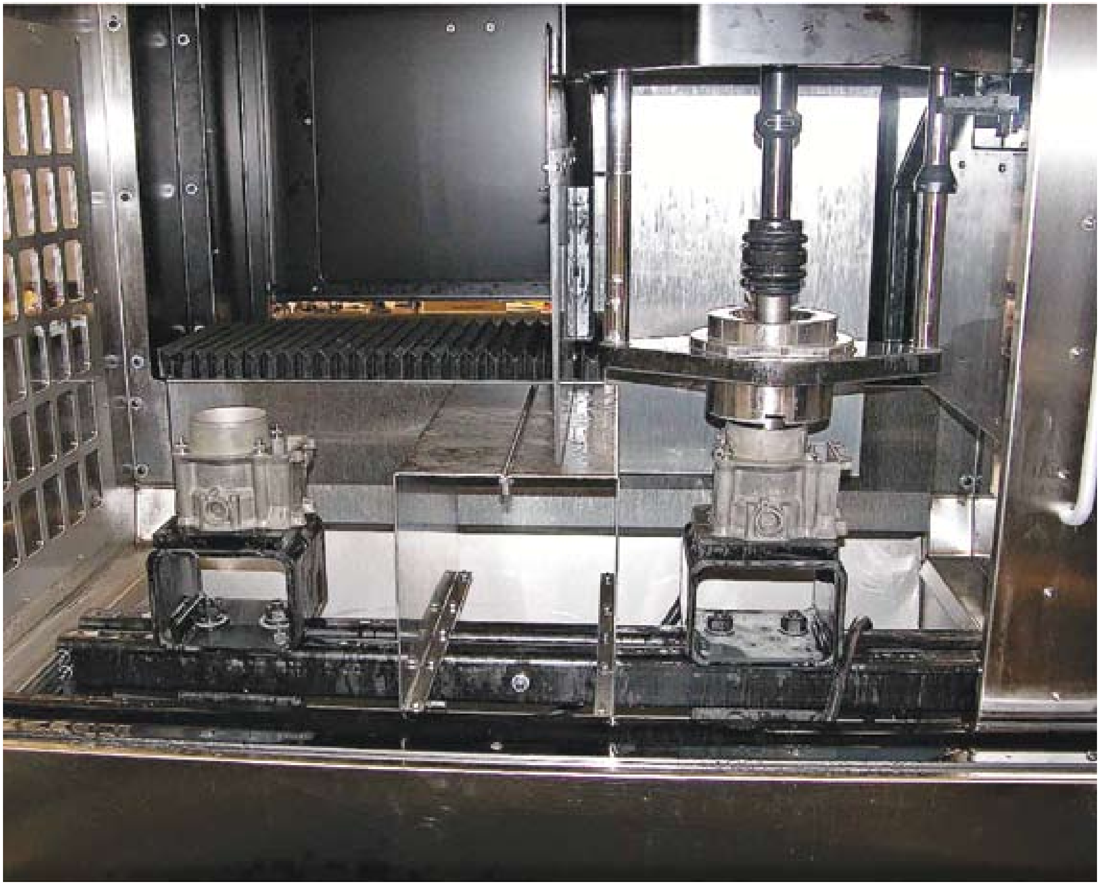
Tests have shown that high-precision bore geometry and a fine finish reduce vibration, friction and blowby because of improved fit and alignment of the piston and cylinder. A precise piston/cylinder interface contributes to better sealing and lubrication, greater combustion efficiency, more usable power and lower emissions. Honing can produce this geometry and surface finish with the consistency needed for mass production.

Honing Development

Honing is an abrasive machining process whereby a tool with expanding abrasive stone assemblies rotates in the cylinder bore while the tool or the part reciprocates rapidly. Because the cutting points of the honing abrasive are so small and numerous, heat and stress in the workpiece are minimal. As a result, the surface can be finished to a specified roughness level. In terms of smoothness, a finish finer than or equal to 3.9µin. R_a can be achieved, though smoothness is not an issue on cylinder bores. The more important factor for engine OEMs is the range of surface parameters that can be controlled with honing. These include R_{pk}, R_{vk}, V_o, Mr1 and Mr2.

Cylinder honing first became popular in engine rebuilding during the 1930s, shortly after Joseph Sunnen invented

One of the keys to the performance of engine and compressor cylinders is the crosshatch pattern that honing produces on the bore surface. The honed finish combines a specific quality of bearing surface with a defined crosshatch pattern that enhances axial lubrication transfer.



An ATV engine cylinder is honed to a bore diameter of 3.858", ±0.0005" with roundness and straightness of 0.001" and a surface finish of 12µin. R_a. The bore is Nikasil-plated.

and patented the offset hone head for deglazing cylinder walls during engine rebuilding. He sold this product to shops to "touch-up" cylinders when they installed new piston rings. Where cylinders were resized by boring, Sunnen's hone was used as a finishing operation. The principle that made the first Sunnen hone successful has since been developed into a CNC machining process.

One of the keys to manufacturing engine and compressor cylinders is creating a crosshatch pattern on the bore surface. The honed finish combines a specific quality of bearing surface with a defined crosshatch pattern that enhances axial lubrication transfer. These traits are particularly beneficial for engines and compressors because the environment at the piston ring/cylinder wall interface is extremely hostile, and honing helps these two wear surfaces achieve maximum life expectancy. It also reduces oil burning. In addition, today's CNC honing systems can also correct a multitude of errors in bore geometry, such as barrel, taper, centerline bow, roundness and straightness.

A die-cast, two-cycle chainsaw engine with an interrupted bore is chrome-plated and then honed to a 0.0002" tolerance on diameter, straightness and roundness.

Honing, especially on a CNC machine, can achieve sizing accuracies of ±0.000010". The high resolution on the tool feed systems of CNC machines minimizes process variability, so honing is ideal for high C_{pk} process control. In a production environment, honing is a more capable process than reaming or boring because, as a rule, abrasive machining processes are inherently more accurate and controllable than chip cutting processes. A honing stone, for example, cuts to the same size and same surface finish throughout the life of the tool, from the first part to the last. A chip-making tool will change over the course of its life. Reaming and boring have sometimes been considered adequate finishing steps for small engine bores, compressors and hydraulic components. However, the drive for performance improvements in power and efficiency—with lower emissions and fewer maintenance problems—is leading small-engine and compressor makers to adopt honing to set the final bore geometry, size and finish.

Process Development

To meet the needs of OEMs producing less than 50-hp engines and compressors in volumes of 300,000 to millions per year, honing machine builders have developed solutions that differ from the hard automation that works well in the automotive industry. Hard automation means a manufacturing system is designed for one purpose only. That system typically performs very quickly and very well. However, changeover to a new part design or a new part altogether can be time consuming and costly, which is typically the case for traditional U.S. auto manufacturing transfer lines. This contrasts with flexible automation, which is designed to adapt readily to changes in parts, processes and manufacturing strategies.

Honing machines must be designed for the needs of different manufacturers. For example, makers of small engines and compressors differ widely in their part volumes, use of automation, cost objectives, part weights, operator skills, geometry and tolerance requirements, quality of upstream processes, quality of die castings and use of cylinder platings and liners. If it operates in a low

A cast iron refrigeration compressor (top) has three bores that are honed with a two-stage PH hone head that can perform both rough and finish honing with in-process air-gaging built into the head.

labor-cost region, an OEM might prefer to use manual load/unload machines, even in a plant producing millions of cylinders per year. Manufacturers may line cylinders with cast iron, Nikasil or chrome plating or make the cylinder from high-silica aluminum, all of which will affect the selection of abrasives and honing machines. Casting quality must be consistent to achieve a consistent honed surface. Abrasives must be matched to balance the desired finish and quality with cycle time and cost of consumables.

Where honing is added to a production line, process development helps establish the right types of machines and abrasives to meet an OEM's overall part-making objectives with an output that synchronizes with upstream and downstream processes (Takt time, or the rate at which parts must be produced to meet customer requirements). Changeover time and flexibility are important, too, because small-engine part manufacturers typically make a higher number of parts in lower volumes than comparable large-engine operations.

For example, several small-engine OEMs are using the Sunnen ML-5000, KGM-5000, SV-1000 and SV-300 sys-

Early honing experience pays big dividend

JIM BRIZZOLARA, PRESIDENT and CEO of HydraForce Inc., Lincolnshire, Ill., credits lessons learned on a Sunnen hone at his first job in 1966 in a hydraulic valve factory with helping him understand how precision bore finish and geometry can fine-tune a valve's performance. Fast-forward to 2007 and Brizzolara has used that knowledge to help build the company he co-founded in 1985 into a supplier of cartridge valves and integrated-circuit manifolds.

Brizzolara considers honing one of the company's core competencies. HydraForce uses nearly 36 Sunnen conventional honing systems at its plants in the U.S. and U.K. The machines produce the final size and geometry of valve cages and other critical parts to less than 0.00005" accuracy and customize the surface finish to specs tailored for various mating components used in the products. Brizzolara said precise size and surface finish on mating parts help eliminate leakage and ensure consistent performance on electrically actuated models under low-voltage conditions, which are often encountered with low batteries on mobile equipment.

HydraForce uses conventional honing, which takes a little more time, rather than single-pass honing, which is a quicker and less costly process. The process typically involves roughing on a Sunnen ML-5000 Power Stroke machine and finishing on CGM and KGM 5000 Krossgrinding machines. CBN abrasive is used for roughing. Finishing passes typically use plated-diamond tooling on the

HydraForce operator setting up a Sunnen KGM 5000 Krossgrinding machine, which is used for finishing.

Krossgrinding machines, which can control hole size to accuracies of 0.000010".

Although HydraForce machines stainless steel and other materials occasionally, most valve cages start as 12L14 or 12L15 steel that is carburized to a hardness of about 60 HRC after screw machining. "Any competitor can purchase screw-machined components from suppliers just like ours, but what sets us apart is our knowledge of how the final fit and finish on mating parts can be optimized with honing," Brizzolara said. "Conventional honing can really make a difference in how a product performs. It's not just the size control; it's the surface finish and crosshatch pattern you put on the bore of the cage. Our tight control of operations that produce the fit, finish and clearance of mating and sealing components produces a more efficient hydraulic circuit."


Cartridge valves manufactured by HydraForce.

Conventional honing provides a number of advantages for finishing valve cages, according to Brizzolara. A conventional honing mandrel, which contacts almost the full length of the bore while the part reciprocates, corrects any geometric errors from screw machining by improving straightness or cylindricity and eliminating distortion caused by heat treating or stress relief. A single-pass honing tool, on the other hand, is tapered, so the small area of the tool representing final size tends to follow the cage bore's path, making it less likely to correct a curved bore.

Conventional honing also produces a crosshatch pattern on the bore surface, while single-pass honing produces a helical pattern on the surface. "The crosshatch surface ensures a consistent, full-length flow path for lubrication around the mating parts of the valve," Brizzolara said. "It's the same surfacing technology used in automotive cylinder bores, particularly in performance racing."

In addition to the crosshatch, HydraForce also measures and controls surface roughness. "A superfine finish without crosshatch actually diminishes lubrication between mating parts, thus increasing friction," he said. "We control R_a on our honing, and for certain parts we will control R_k and R_{pk}. The valleys improve lubrication, but the peaks cause friction, which leads to sluggish operation." HydraForce customizes the surface roughness for optimal valve performance, based on the nature of the mating parts.

Conventional honing also minimizes the need to deburr parts. Single-pass honing produces more burrs in the cross-holes of the cage. "Single-pass honing mandrels tend to fold, tear and push more material, while conventional abrasive tools cut the material, though speeds, feeds and pressures need to be controlled to achieve the best result," Brizzolara said. "We document these parameters to develop best practices, stick to them, then try to improve them as we go on."

All of the honing machines at HydraForce have a two-fixture method for maximum in-cut time, allowing the operator to load a part while the other is in the machine. Operators air-gage every part after honing, and lot sizes run from a few hundred pieces to several thousand (honing is the only batch process in the plant due to cleaning requirements). Part diameters range from 0.097" to just over 1".

—Phil Hanna, machinery product manager, Sunnen Products

tems, which can be used in manual or automated production environments. Using metal-bond abrasives with a tool feed system capable of adjustments in increments of 0.00001", the KGM and SV series machines can precisely set bore diameter, straightness and roundness.

Two-cycle engines

Two-cycle engine cylinders present several honing challenges. A two-cycle cylinder is often a blind-bore that is sometimes tapered. There are sizable ports in the cylinder wall, so it is critical to avoid washout around the ports, a honing defect caused by improper tooling that compromises cylinder seal characteristics. Most of these cylinders are chrome- or Nikasil-plated, which creates its own challenges because there is some initial nonuniformity in the surface that has to be eliminated. Chrome's hardness can also lead to eggshelling if the abrasive grit is too large. (Eggshelling is surface cracking that sometimes leads to flaking.)

All of these issues have been addressed in a recent product improvement program for a leading maker of small engines. The company is using 11 Sunnen machine cells at a plant that turns out 4 million engine cylinders a year in 20 different models.

The manufacturer's basic engine cylinder starts as an aluminum die casting. The castings are aged to normalize them, bored and machined on CNC machining centers. The parts are then deburred before being chrome-plated.

For this application, a custom TC (two-cycle) tool is equipped with a large number of stones aligned in an array for a ported, blind, tapered bore. The large number of stones produces superior roundness and finish consistency. The TC tool avoids washout around the cylinder ports, which helps maintain the cylinder's seal characteristics. Washout occurs when the honing abrasive tries to bulge out through the port opening as it is forced against the cylinder wall. This could produce a radius on the port

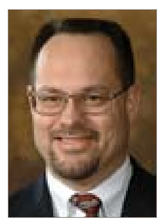
A two-cycle honing tool for working inside an interrupted blind-bore.

opening's edge where a sharp 90° edge is needed, resulting in some irregularity of roundness and a small degradation of ring seal. To hone a bore with a keyway or open hole in its wall, the stones must be of a size and arrangement that bridges the opening. A rigid tool also eliminates the tendency to washout.

As a final step, the bore is plateau honed, a process where a first, rough set of stones is followed by a series of smoother stones or brushes. Plateau honing increases the life of cylinders and piston rings by imparting a surface finish on the cylinder wall that is "broken in" before the engine's initial start. Plateauing creates a metallurgically stable surface on the cylinder's wall, removing loose, torn or folded material. A machined metal surface typically consists of microscopic peaks and valleys. Plateauing cuts down the peaks to produce a bearing area that meets an exact specification, while leaving the valleys. This produces a smooth surface with high sealing contact between the cylinder and piston ring, while leaving the crosshatch valleys to retain lubrication.

After proving honing's value on cylinder bores, this small-engine manufacturer is evaluating improvements gained from honed connecting rods. The plant recently purchased a vertical CNC honing system that can automatically control hole size to accuracies of 0.00001" without operator intervention.

The challenges in honing small engines and compressors are similar to those of other advanced machining processes. While process development is always crucial, CNC and even manual honing systems are proving an important part of the technology behind the improved efficiency, life and performance of today's compressors and small engines. **CTE**



About the Author: *Rich Moellenberg is manager, global sales services for Sunnen Products Co., St. Louis. He holds a BSME degree from the University of Missouri-Rolla and has 25 years of honing application development experience. For more information about the company's honing machines, call (314) 781-2100 or visit www.sunnen.com.*