



SUNNEN PRODUCTS COMPANY

7910 Manchester Ave. St. Louis, MO 63143 U.S.A.
Phone: 314-781-2100
U.S.A. Toll Free Sales and Service 1-800-772-2878
Fax: 314-781-2268
International Fax: 314-781-0692
www.sunnen.com e-mail: sunnen@sunnen.com

SUNNEN PRODUCTS LIMITED

No. 1 Cenetro, Maxted Road
Hemel Hempstead, Herts HP2 7EF ENGLAND
Phone: 44 1442 39 39 39 Fax: 44 1442 39 12 12
www.sunnen.co.uk e-mail: hemel@sunnen.co.uk

SUNNEN AG

Fabrikstrasse 1
8586 Ennetaach-Erlen SWITZERLAND
Phone: 41 71 649 33 33 Fax: 41 71 649 33 34
www.sunnen.ch e-mail: info@sunnen.ch

SHANGHAI SUNNEN MECHANICAL CO., LTD.

889 Kang Qiao East Road, Pudong
Shanghai 201319 P.R. China
Phone: 86 21 5813 3322 Fax: 86 21 5813 2299
www.sunnensh.com e-mail: sales@sunnensh.com

SUNNEN ITALIA S.R.L.

Via Stelvio 12/15
20021 Ospiate di Bollate (MI) ITALY
Phone: 39 02 383 417 1 Fax: 39 02 383 417 50
www.sunnenitaliaia.com e-mail: sunnen@sunnenitalia.com



For more information
or to order online visit

www.sunnen.com

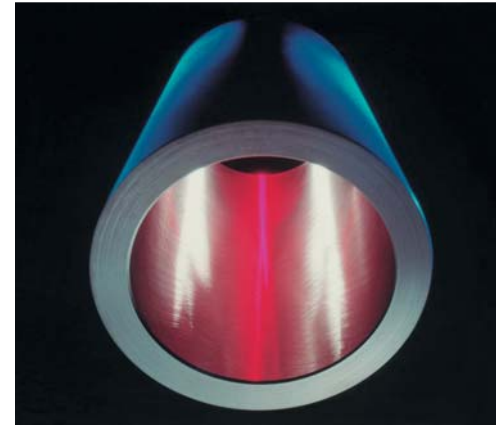


HONING

Technology, Tools and Machines



PORTABLE HONING



Miniaturization of technical components and the frequently required high pressures and mechanical loads have led to higher precision demands for small workpieces. Since these processes are usually done by smaller suppliers to the large final user, it was highly important to provide the supply companies with the means of machining high accuracy at reasonable cost. This is provided by the flexibility of using standard machines, which can be used as building blocks, if more capacity is required.

Automation of honing machines also help lower the cost of honing.

Worldwide, the small but interesting machine market offers ready solutions for varying, specific problem points. The relatively new technology of honing has gained a secure place in manufacturing. Very high quality of finished bores, even for complicated bore geometry and interrupted holes and small batches have led the honing process to be the ever more economical alternative.

Honing offers users chances for optimizing their processes and increasing their productivity. The example of honing conical bores shows how today's technology can create very great savings compared to the conventional methods. The increasing demand for high precision parts in large quantities, like for hydraulic components or injection pumps, contains great potential, as well in technological as in economical view. In competition with other metal-removing machining methods honing often has the decisive advantage.

**Trend to
miniaturization**

**Standard and
universal
machines with
great flexibility**

**A method
with great
potential**

PORTABLE HONING

Reduction of non-productive time

Manual Feed

All portable honing tools have manual feed. The smaller tools can be pre-loaded, then have the stone retracted by a lever and stored by a spring. This will reduce the time required for honing. Larger diameter portable hones are available with a feed wheel, which can be used while the tool is rotating (Picture 42). Further time saving can be achieved by a quick-change coupling or the above mentioned retraction lever, which allows quick withdrawal from the bore.

42
Larger diameter portable hones are equipped with a feed wheel.



Portable honing tools have a large variety of stones available. The choice depends on the type of material to be honed as well as the amount of stock removal.

Great flexibility

Typical abrasive for rough honing is aluminum oxide; for finish honing silicon carbide of several grit sizes is available.

The quick change from one grit size to another and the ease of compensating for stone wear give portable honing a high degree of flexibility, which methods like reaming can't provide.

At a glance

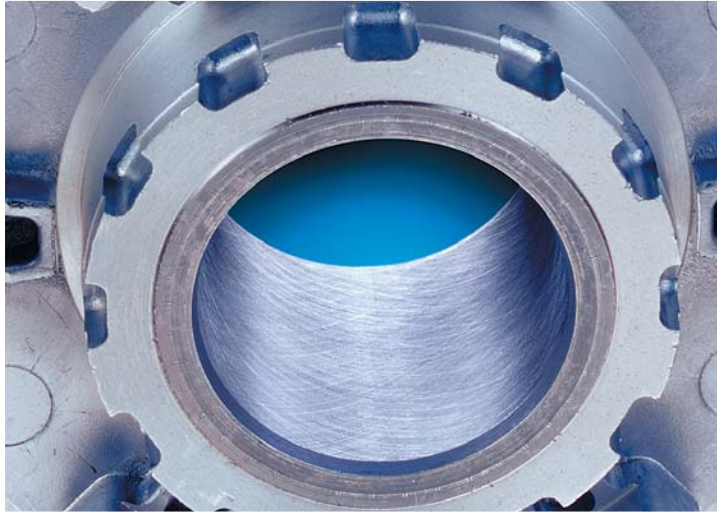
Honing is a high quality bore finishing method that has benefited greatly from technological developments in synthetic abrasives and high-powered tools in the last few years. Honing used to be known as only a finishing operation, is now known to be capable of doing several operations at once.

Table of Contents

Introduction	2-4
Technical Basics	5-18
Oscillating Machining	11
Single Stroke Machining	15
Comparison to other Fine Machining Methods	17
Efficiency of Honing Technology	18
Tools and Wear Items	19-28
Tools for Oscillating Machining	21
Tools for Single Stroke Machining	24
Abrasives	25
Coolant Lubricants	27
Honing Machines	29-45
Machines for honing small batches	34
Machines for honing small to medium batches	36
Machines for mass production	38
Large Diameter Machines	43
Portable Honing Tools	46-49
At a Glance	48

INTRODUCTION

1 Typical structure of a honed surface



What is honing

Honing is a final finishing operation conducted on a surface, typically of an inside cylinder, such as of an automotive engine block. This metal removal process is used after casting, sintering, drilling, boring or remaining to obtain precise bore geometry and surface finish. Abrasive stones are used to remove minute amounts of material in order to tighten the tolerance on cylindricity.

Honing, in the last decade, has become a process better described as “bore finishing” because the amount of stock removal and the rates at which it can be removed have increased substantially.

Brief history of honing

The idea of honing – predetermined grinding movement and universal stock removal – began centuries ago. In the 1500’s Leonardo da Vinci developed a tool for the machining of wooden tubes. The tool used a combination of rotation and stroking and incorporated an abrasive grit.

Honing tools, as we now know them, were developed at the beginning of the 20th century primarily to improve components in the internal combustion engine. The first honing tools were wooden sticks with abrasive paper. Springs forced the sticks against the cylinder walls. Soon, more complex tools were developed. In 1924, a five-bladed stick honing tool with a universal joint and spring feed was patented. In the early 1930s, honing was first used in a high production application – stack honing of connecting rods.

PORTABLE HONING

Portable honing tools are available for diameters of about 35 to 550mm (1.375 to 22 inches). The tools have expandable honing stones and are meant to be multi-stroked. The recommended surface speed is between 30 to 60 m/min (Optimum rpm is calculated by dividing 1200 by the diameter in inches, or dividing 30,000 by the bore diameter in millimeters... for example $1200 : 6 \text{ inches} = 200 \text{ rpm}$, or $30,000 : 150 \text{ mm} = 200 \text{ rpm}$).

Drives can be electric or air drills (Picture 41). If two universal joints are used, drill presses can also be used.

If the workpiece is mounted on a table, which can freely move sideways, then the portable honing tool can be rigid mounted. The slight sideways motion of the honing tool will not cause any problem, because it will be accommodated by the floating table.

Floating location of workpieces

Therefore honing with portable tools will offer these advantages of honing:

- roundness
- no bellmouth
- surface finish and size in one operation
- precise results for interrupted hole surfaces
- fast change of honing stones when changing from rough to finish honing (in case of large stock removal)

PORTABLE HONING

Portable honing tools

In cases where the workpiece dimensions or other conditions prevent handling or chucking of the parts, portable honing tools can handle the job and create u-accuracy. The main use for these tools is repair, but they are also used in manufacture of parts that are too bulky to be honed on machines. Portable honing tools can achieve surface finish qualities down to $R_a = 0,2 \text{ mm}$ (8 microinches), and size tolerances down to $0,01 \text{ mm}$ (0.0004 inch).

Drive by drill motor



41

Portable honing tools permit precision honing in place or of bulky work.

Stroking is done by hand



Typical applications are:

- reworking bearings
- reconditioning of compressors, engines and hydraulic cylinders
- the repair of production machinery in place
- the removal of distortions, caused by installation or heat effects

INTRODUCTION

Honing advanced with the development of more advanced systems – vertical and horizontal machines – with more precise adjustments and improved abrasives. Synthetic diamond abrasives were first used in 1954. The introduction of Cubic Boron Nitride (CBN) abrasives changed the perception of honing in the 1980s. Instead of simply polishing a thousandth or two (0.05 mm) of material, honing is now a productive, fully-capable machining process. Applications from rough honing to final surface finish measured in microinches are now possible with a total system approach to honing – machines, tools, abrasives and coolants.



Total system approach

2 Automated Multispindle Machine (right) create u-accurate and geometries and surfaces with short piece times..

New technologies allow the removal of .016 in (0.4 mm) or more during rough honing from a hard steel bore in 40 seconds, 1 in. diameter (25 mm) by 1 in. length. Roundness, straightness and cylindricity can be held to .0004 in. (0.01 mm) or better during roughing operations and less than .000040 in. (1 micron) during finishing. Honing is now both attractive and cost effective.

Attractive and economical

The need to pre-machine is often eliminated because even large errors in geometry can be remedied by honing. In only one step, accuracies measured in a few thousands of a millimeter are achieved for all commonly used materials including glass and ceramic.

Honing is a time-saving process as it requires only a few seconds per part. In applications where one operation is not enough, honing systems with multiple spindles achieve the required surface finish and accuracy in several steps but with only one chucking – a time-saver.

INTRODUCTION



3 ▶
The range of applications for honing reaches from the smallest valves to the cylinders of large internal combustion engines.

Possible to integrate into automated production

Many honing systems are now automated. In the last decade, the advent of single stroke honing® with high-speed tools in NC machines has provided a cost-effective solution for high production applications. Portable honing tools and simple, manual honing machines are still adequate for small lots.

Typical applications for the honing process include (Picture 3):

- gears
- bushings
- fuel injectors
- hydraulic valves
- valve bodies
- automotive engine components

The dimensions of honed bores range from less than one millimeter (0.040") up to 900 mm (35.4") in large piston engines.

Modern engines can credit the honed bore for the power output and long service life.

Other benefits of honed bores include:

- secure signal transmission,
- noise reduction;
- and increasing the energy efficiency of aggregates and hydraulic valves.

HONING MACHINES



▶ 40 Automated Multispindle Machine (left) create microinch accuracies and geometries

The combination of a precision machine, exact feed-up of tools, fast action, and fine measurements are required for honing conical bores. With exact control of stone feed and a conical honing tool it is possible to hone long conical bores, such as extruders for plastic manufacturing, and get microinch accuracy, (Picture 40).

Honing of conical cylinders...

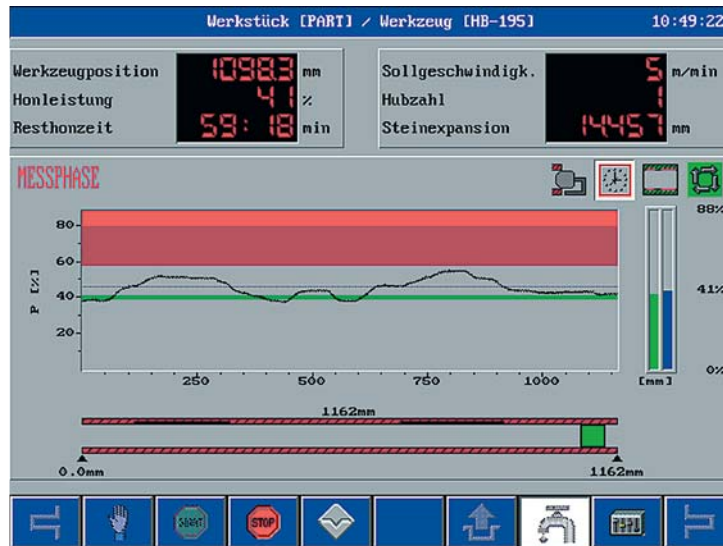
In this case honing replaces several steps of conventional manufacture and creates considerable cost saving. The honing time per workpiece is about 10% of the conventional method.

...with considerable time saving

HONING MACHINES

Equipment details

In work set-up these machines have similar requirements as the smaller horizontal honing machines. Modern numeric control with touch screen and program to be installed by the operator, also visual observation of tool position spindle load, cycle time and feed force (Picture 39). In addition, long-reach honing machines can have electronic feed system and view of the tool expansion, as well as the variable power limits.

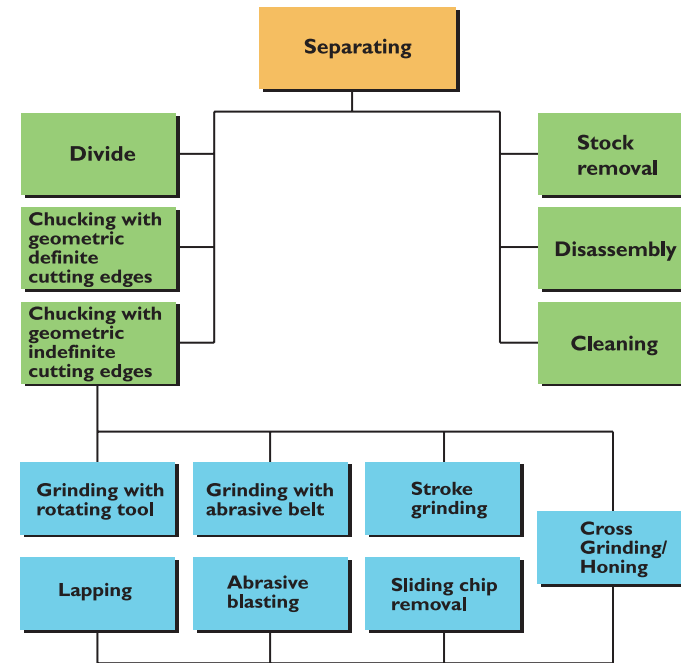


39 Automatic correction of tight spots, and control of tool feed add very importantly to assurance of honing process

Process safety

Tight spots in long bores can be a problem or even a danger for the tool or the operator. Therefore a programmable overload protection and a program for automatic correction can be a very valuable feature. The critical areas will be detected by the spindle load, and can be corrected by dwelling in those areas. Only after the tight spot has been opened up will the long stroke resume. To make this possible the machine will need a sensitive measuring system, coupled with intelligent communication to the machine control. In addition, a graphic and numeric display will show the conditions in real time.

TECHNICAL BASICS



4 Various methods for fine machining according to DIN 8580.

Honing combines excellent geometric accuracy, high surface quality and rapid stock removal so it is a cost effective production in one single operation. The following components have decisive influence on the work process:

- workpiece
- tool
- rotational speed of the tool or the workpiece
- coolant/lubricant
- work holding device
- axial movement of the tool and/or the workpiece and machine.

According to standard DIN 8580 honing belongs to the machining method with geometric indefinite cutting edge. This group includes grinding, lapping, and abrasive blasting (Picture 4). Characteristic for all these methods is stock removal by means of irregularly shaped grits of hard materials. Most are based on a straight-line path; honing (cross grinding) has the paths criss-crossing.

DIN 8580

Compared to processes such as boring, reaming, grinding, etc., honing requires about 10 times as much energy per volume of



5 ►
Honing removal stock with low pressure and large flow of cutting oil.

removed stock. Other processes put most of the heat in the chip, while honing puts most of the heat into the workpiece. But honing uses relatively low pressure and continuous large area contact between tool and workpiece. The cooling lubricants (honing oil) take care of the removal of the chips and aid in cooling. The “coolants” are usually oil, and in addition to cooling they have important chemical properties, which aid in the cutting action (Picture 5).

In contrast to cylindrical grinding, honing does not cause a so-called soft skin with micro tears. Since the border zone structure of the metal during the honing process is exposed to stroke as well as pressure, any changes in the metal structure are actually beneficial. Therefore honing is eminently suitable for highly stressed thin walled workpieces or workpieces with many interruptions of the surface.

The classic honing tool (see Chapter Oscillating machining, Page 15) consists of at least two guide bars and a bar-shaped abrasive body (honing stone). It follows the axis of the pre-machined bore. The closely defined feed during the honing process is actuated by a cone or wedge inside the honing tool. The stock removal is always done with a large number of abrasive grains, which are arranged in many layers, and fastened to the stone holder.

Tool construction

Tube Hones

It is possible to hone long parts in a vertical position but it will require more time and effort to chuck and measure. Also these machines require large space. These are usually custom-made applications for high production.

On the other hand standard horizontal honing machines can be easily installed. Because of their flexibility these machines are suitable for job shops for honing a variety of workpieces.

The spectrum of applications range from gun barrels, hydraulic cylinder up to cylinders for large ship engines and landing gear for aircraft. They all can be honed efficiently and economically by this type of honing machine.

Long-reach honing machines have these requirements:

- long spindle travel
- great rigidity of machine bed and tool
- very sensitive detection of overload condition

Universal standard long-reach honing machine can hone parts up to 10 meters in length (33 feet) with diameters from 25 mm (1 inch) to 1000 mm (40 inches). The tool travels together with the spindle drive, while the drive shaft is supported several times along the machine bed. If required, this machine type can be optimized for extra-high stock removal rates. The manufacturer of these machines can offer even greater lengths. There are also variants for long workpieces with small diameters of from 3 mm (0.118 inch) to 25 mm (1.000 inch) (gun barrels).



Standard machine with horizontal multi-stroke spindle

Further application spectrum

◀ 38
Horizontal tube hone for multi-stroke honing of very long or bulky workpieces.

HONING MACHINES

... for single-stroke[®] operation

Another new vertical honing system, the SV-1000, (Picture 37) is useful for mid-to high-volume production in small bores from 3mm to 65mm (.120 to 2.56 in). It has a Windows[®]-based PC industrial touch screen control panel featuring easy-to-use drop down menus. The set-up is fast and simple with a handwheel controlled servo axes: feed, stroke and optional rotary table.



37 ►
SV-1000
Vertical Honing
Machine

Quality assurance

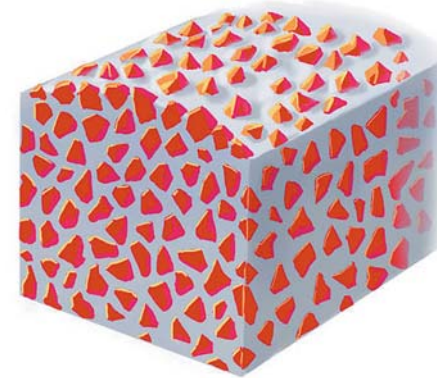
Quality assurance for honing machines for high production is achieved by integrated or adapted inline measuring systems. The measurement parameters are obtained by air or mechanical systems and are evaluated by computer. In the case of multi-stroke honing, measurement can be done continuously during the honing operation, and feed the tool up accordingly.

The most advanced NC with remote servicing by modem and quality assurance connection

Honing machines for high production need high-powered numeric control, which supports a dialog-oriented program and has many places for storage or work programs. Once programmed, the machine takes over the control of all work parameters, the necessary changes of spindle rotation, dwell, and the determination of the optimal honing times per part, and the determination of tool life.

Besides the above described machines for multi- or single-stroke[®] honing of from small valves to large engine blocks, standard machines are also available for honing long tubular parts.

TECHNICAL BASICS



6
The stone consists of many layers of grit, which come into action one after the other. Worn grits break out and are replaced by sharp grits underneath.

Long tool life

When one layer of grits is worn down, the dull grains will break out of the bond, so the layer of grits underneath can take over. (Picture 6). The success of honing depends on the proper ratio of grit to bond for the particular condition, and it is a very important factor for the efficiency and predict-ability of stock removal.

Classic honing stones have the ability to continuously sharpen themselves. In contrast, tools with geometric defined cutting edges will wear and get dull, a honing stone is not affected by wear, and it will not change cutting action or resulting accuracy. The life of a honing stone can be more than 50,000 bores; in contrast, the life of a tool with geometric defined edges is typically between 500 and 800 bores.

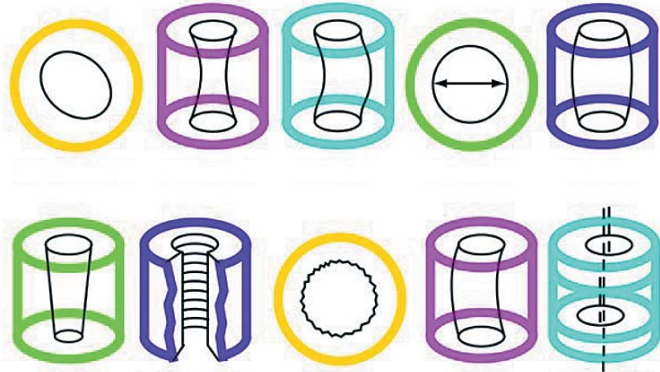
TECHNICAL BASICS

HONING MACHINES

Long tool life

Modern high-tech abrasives can hone almost all materials used in industry such as hardened or soft steels, cast iron, copper alloys, light metals, sintered materials, hard chrome, ceramics, glass and titanium. **Picture 7** illustrates how honing can correct all bore problems -- out-of round, wavy, undersize, barrel, taper, and remove roughness caused by pre-machining, and create the optimum surface finish for each application. (See chapter Oscillating Machining, page 15).

7
Modern abrasives can correct bore inaccuracies, pictured here.



36
SV-200 Vertical Honing Machine

Vertical honing machines such as Sunnen's SV-200 combines power, precision, durability and technology to deliver mid-to high-volume manufactures the lowest cost per honed piece.

Vertical machines

The SV-200 incorporates an all new stroking system that produces a true vertical stroke and can dwell in any part of the hole, end-to-end, selectively removing stock for the straightest, roundest bore possible.

HONING MACHINES

Single-stroke vertical machines

Unsurpassed in flexibility and economy are modern multi-spindle vertical machines (Picture 35), used for single-stroke honing. Standard machines are available with spindles arranged in a circle or in a row to accept modern diamond (electro-plated diamond) single-stroke honing tools, and this makes for fast, very economical high-accuracy processing of bores in small parts. These parts are being brought to the floating tools by means of linear or knee-action robots.

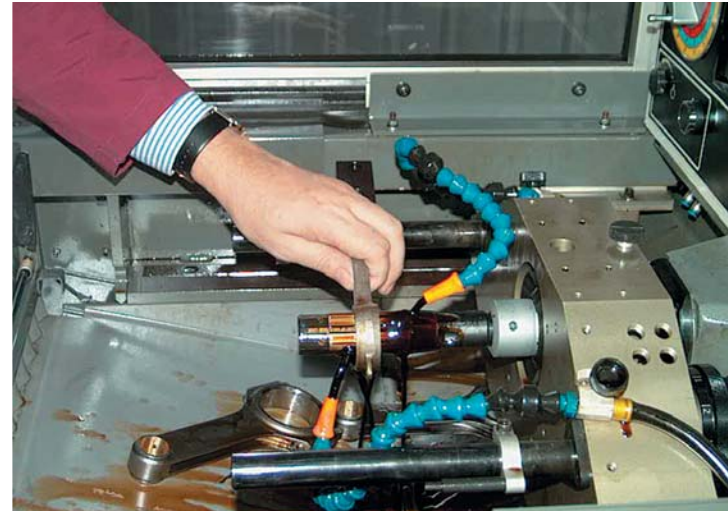


35 Multi-Spindle Vertical Machines with round table for single-stroke honing of small parts require very little floor space.

Modern machines require minimal numbers of actions for adjustments, and setting the parameters and programming is very simple and not labor intensive.

TECHNICAL BASICS

Newly developed rigid multi-stone, segment and sleeve hones, equipped with high-performance abrasives, will not only correct bore problems, but will correct the location of holes. Even difficult bores, (bad ratio of diameter to length, tandem bores, bores with keyways or splines, or blind holes) can be successfully honed.



Fixturing of workpieces

8 Convenient workpieces, such as connecting rods can be honed floating (not fixtured) on a simple honing machine with horizontal spindle.

Rigid chucking -- a rigid connection between the tool and the workpiece -- is not done with honing. Parts that are small or easily distorted do not have to be fixtured and can be honed floating, which eliminates centering the workpiece.

TECHNICAL BASICS

Universal joints

This also comes in handy for parts with shapes such as connecting rods or transmission parts. If it is necessary to fixture the workpiece such as an engine block then the honing tool will float, by means of universal joints (Picture 9). This also prevents the possibility of shifting the centerline of the workpiece during honing.



9
Large workpieces in fixed position being honed with double universal joint.

Two principles

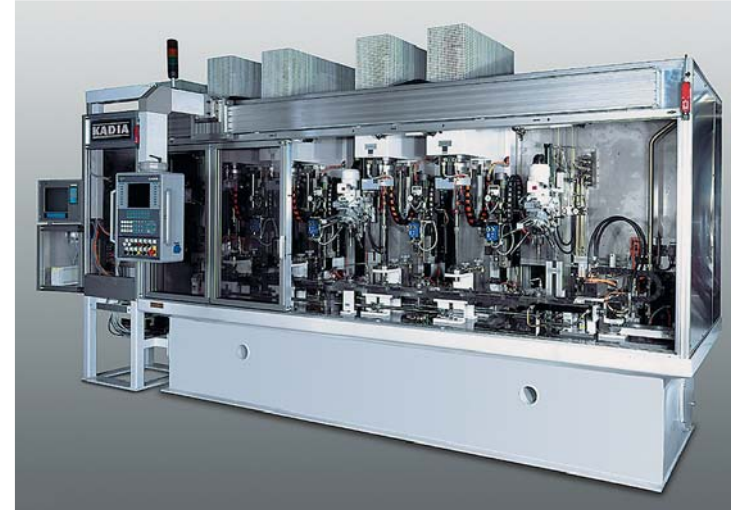
To achieve the desired structure, the microinch-accurate size as well as the shape accuracy --roundness, straightness and cylindricity of a bore -- it is necessary to guarantee the correct amount of stock removal through the entire length of the bore.

Honing of bores can be done in two distinctly different ways:

- oscillating method – the classic honing method – and
- single-pass method – also called microsizing.

HONING MACHINES

There are no limits to the configurations of honing machines for high production. Vertical machines as tall as the ceiling are used for honing the main bearing saddles of truck engines, and fully automated transfer lines for honing the cylinders of engine blocks (Picture 34). With these custom-built special machines it is possible to completely machine even complicated workpieces.



34
Automated Multispindle Machines create microinch accuracies and geometries.

Even diverse machining operations, such as boring and honing can be done in one chucking.

But the subject of this book is not special machines for high production, but the fact that relatively low-priced standard machines are just as capable for productivity, precision, and reliability. These are important points to consider in the light of increasing diversity in designs and shorter life span of technical products.

Special machines

Standard machines

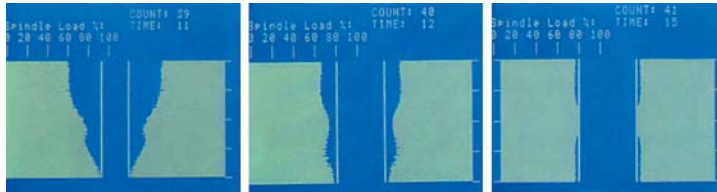
HONING MACHINES

Real time display

To allow individual correction of bore geometry it is very useful to have real time display of the shape of the bore while it is being honed (Picture 33). This makes it possible to take appropriate action, such as dwelling at the tight spot of the hole. If the machine is equipped with automatic compensation for cor-

33 ▶

Real time display makes it possible to see the actual shape of the hole being honed, and allows appropriate corrections.



recting hole geometry, it is easy to include horizontal machines into a chain of machining processes. This is especially important for blind hole honing.

If the machine has the ability to store programs, it will be easy to integrate several automated programs and allow the use in mass production.

Program storage

For high production, there are clear conditions, namely:

- low machining time per part
- high assurance of process result
- higher degree of automation

Machines for mass production

Only in exceptional cases will these demands be answered by the above mentioned single-spindle machines, such as when using a chain of machines to get maximum flexibility.

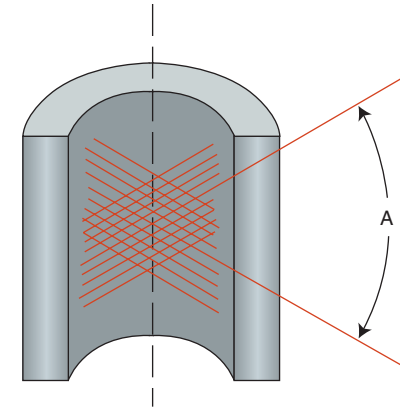
Multi-spindle NC machines

Much more often the mass production facility uses multi-spindle machines with complex numerical control, including all measurement, compensation and process optimizing functions. This way very high process reliability and a practically operator-less production can be assured. This is very important for mass production. Usually the workpieces are being loaded and unloaded onto the honing machines by means of robots, which can also be integrated into a chain of machines.

TECHNICAL BASICS

Oscillating honing, also called multistroke honing, uses repetitive strokes through the hole. Together with the rotation of the honing tool it creates the typical crosshatch pattern. The stroke speed is almost constant during the entire length of the stroke. It stops at the end of the stroke to reverse itself. Since the rotational speed is also constant, the entire length of the honed tube will have a consistent crosshatch angle, except for the area close to the ends of the hole, where the need to stop and reverse will create a somewhat smaller angle (Picture 10).

Oscillating honing



◀ 10
Automated Multispindle Machine (right) create microinch accuracies and geometries.

To improve accuracy, it is possible to selectively dwell the honing tool. This is necessary when honing blind holes, that is holes which have no opening or no relief at the blind end, which would make it possible to stroke beyond the end of the hole. Dwelling, combined with short strokes, will allow even stock removal all the way to the bottom. But blind holes require special tools and machines with special software or a very experienced operator.

Dwell



11

Multi-stone tools for honing large cylinders

Honing Methods

Oscillating honing is usually done with single-or multi-stone tools (Picture 11).

Honing preferred for manufacture and repair

The abrasive bodies will first touch the tightest portions of the hole. There they work with low cutting pressure, which then increases in order to remove larger amounts of material to arrive at the desired diameter, geometry and surface quality. Honing is the preferred method for the manufacture and repair of internal combustion engines and compressors for hydraulic equipment. Open crystalline surface is desired,

Machines equipped with numeric controls are economical because they offer easy retrieval of programs and short set-up times. If the job requires an additional operation, such as brushing of high-alloy aluminum, it can be done by using two-stage honing tools, which require practically no additional honing time. These tools contain two different types of stones and/or brushes, which are actuated by the tool's reversal of rotation.

Horizontal work axis



32

Horizontal Single-Spindle machine with two-stage feed system can economically handle small to medium sized lots.

The machine should have a powerful spindle and stroke drive, wide capability of adjustment, automatic tool wear compensation and a two-stage feed system. The first makes certain that the tool will always work at optimum cutting parameters. The last permits working with two different cutting forces in a single operation. This way the main amount of stock removal can be done fast at a high rate. At a definite size it can hone the rest with reduced force to get the best accuracy and desired surface finish and honing time per part will be greatly reduced. Another desirable feature is a gentle approach of the honing tool at the beginning, when the hole is still rough from the original machining operation.

Necessary equipment

HONING MACHINES

Parts that are non-symmetric on the outside, such as connecting rods can absorb the torque of honing by a work rest, while the part is stroked floating across the honing tool. Parts that are round on the outside can be easily kept from rotating by means of a loop-grip holding fixture. This works well even for thin-walled parts (Picture 31).



31
Holding fixture with abrasive cloth for holding workpieces that are round on the outside.

Machines for honing small or medium quantities

Depending on the accuracy requirements, it is economical for both small lots and medium lots, to use numerical control machines with one or two spindles. The latter offers the possibility to do several stages, such as roughing and finishing in only one chucking, without non-productive time between the operations.

The shortened honing time alone may justify the use of these more complex machines for even medium production.

Flexible numeric control

The flexibility of the machine controls and the control of measurements is very important for the economical use in machine shops that supply the mass production companies. If the machine is easy to program and is capable of storing the individual programs for easy retrieval, it is no problem for the supplier to increase the quantity of lots, if necessary by adding more standard machines. This is a good solution for managing entrepreneurial risk.

TECHNICAL BASICS

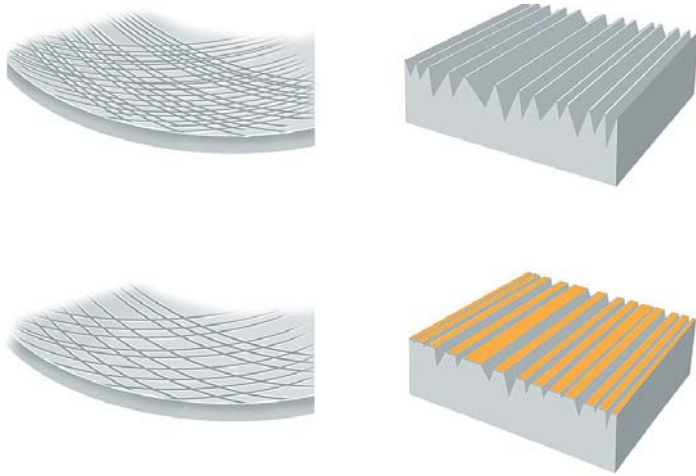


12
Thin-walled cylinder sleeves are honed with low cutting pressure and minimal heat development to microinch accuracy.

which can hold onto lubricants (Picture 12). Too smooth a surface, something that can result from too many strokes with unsuitable honing stones, would be fatal for a piston engine or compressor. The oil film would tear, and piston seizure would result.

Very small diameter holes may be worked with shell tools. The abrasive bodies will first touch the tightest portions of the hole. There they work with low cutting pressure, which then increases in order to remove larger amounts of material to arrive at the desired diameter, geometry and surface quality.

TECHNICAL BASICS



13

By using either very fine honing stones or brush hones surfaces with high plateau areas can be obtained (bottom).

Plateau Honing

The cylinder walls of high-compression engines require a surface finish that has enough of a pattern to hold lubricant, but also has enough peak smoothness to allow the piston rings to seal without any break-in period. This type of surface can be achieved by honing, not just on cast iron, but also on hypereutectic light metal alloys, such as Lokasil, Alusil, Silumal and Duralcan. This usually requires an additional operation. This operation will only uncover the hard phases, therefore it will not change the finished diameter. The silicon crystals of hypereutectic aluminum alloys as well as the graphite islands of vermicular castings can be uncovered with a final honing operation with brushes (Picture 13).

Honing stones consisting of Polyamide threads with enclosed aluminum oxide or silicon carbide grits are used for the plateau honing operation. Plateau honing can do the same thing. It creates plateaus with periodic honing tracks. This is done with a few strokes with honing stones of fine grit ceramic bonded silicon carbide abrasive grits. Typical honing speeds for this operation are 40 to 80 m/min.

For small and medium sized numbers of engine blocks in high-performance shops or in reconditioning shops the word oscillating cross grinding is not popular. It is still called honing and seems destined to remain so. But either way honing, followed by plateau or brush honing ensure high precision and long service life.

HONING MACHINES

The table of the machine is sturdy enough to accept very heavy workpieces, like truck engines with cylinder bores of over 200 mm in diameter (7.9 inches). This type of machine is also capable of a wide range of stroke length, from 20 mm to 300 mm (0.78 to 12 inches). A powerful spindle drive and a sturdy stroking mechanism combine to make this type of machine desirable.

...for vertical...

On a standard single-spindle machine an average V8 engine block can be honed in 40 minutes, removing 0,2 mm/min (.008 inch/min) metal and arriving at the desired overhaul size, geometric accuracy and the required surface structure. Continuously the stock removal and the number of dwells are being detected and displayed on the screen.



30

Standard machine with horizontal spindle for manual multi-stroke honing.

The honing cycles of rough and finish honing are automatic, and the machine stops automatically when the correct size has been achieved.

Honing small and easily handled workpieces in smaller quantities is best done on horizontal machines. Typical applications are repair of any kind of holes, connecting rods, air compressors and small engines (Picture 30).

... or horizontal honing

Machines for small lots

For repairs, prototypes, or other small lots less complex machines with only one spindle and conventional controls have advantages in flexibility and economy. Depending on the size and weight of the workpieces, vertical or horizontal machines are used. For multi-stroke honing of engine blocks vertical single-spindle machines with electro-mechanical or hydraulic drive are best. The honing tools have either narrow stones or abrasive segments. The choice of drive is influenced by the differing efforts the customer wants to put into the job. But work specific reasons can also be decisive. One example is

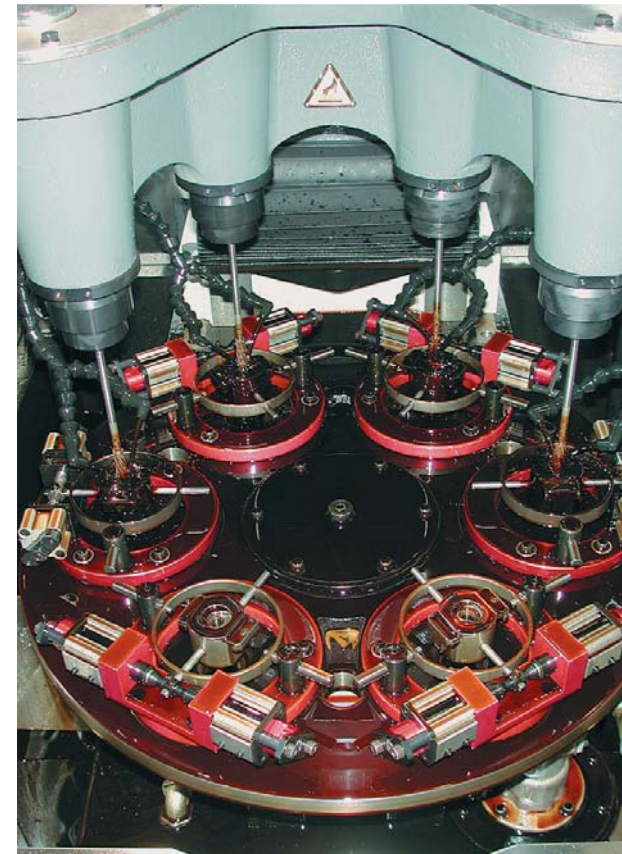
29 ▶
Electromechanical drive on honing machine with vertical spindle for small to medium size lots. This type of machine is especially suited for creating the correct geometry and surface finish in cylinder bores of piston engines.



Single-spindle machines with electro-mechanical drive...

the honing of holes with limited relief at the bottom, where to stroke position has to very accurate. This is typical for automotive engine blocks, where hydraulic stroking would be unacceptable, because of the "sag" at the end of the stroke of a vertical spindle. Machines with electromechanical stroke generation (Picture 29) allow the utilization of the last millimeter of length, thus assuring uniform stock removal and crosshatch angle.

Because of their weight and size these workpieces are clamped on a table or blocks in the machine. Stock removal is done without distorting the bores by the honing tool, which floats on two universal joints. The tool can be inserted into the bore either free-hanging or with a guide bushing.



14
The relatively new method of single stroke honing creates workpieces of high accuracy part after part.

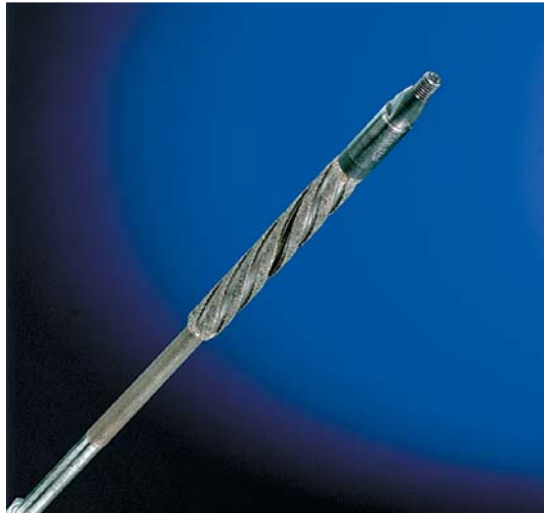
Single Stroke® Honing

With increasing variety of designs of workpieces and therefore smaller lots Single Stroke® Honing has gained in importance. The tool does not expand during the honing process, but it is pre-set to the final diameter and hones the part to final size in just one stroke. The extremely high rate of stock removal makes high demands on abrasives and cutting fluids.

Characteristics of the method

TECHNICAL BASICS

Compared to multi-stroke honing the single stroke[®] method is done at about 10 to 20% less stroke speed; but the rotational speed is about the same. The total stock removal is less. This disadvantage has to be compared to the advantages of less honing time per part and absolute certainty of repeatable final diameter. This is especially important for small diameter cylinders for high pressure applications, where a piston has to be fitted with very little clearance.



15 ▶
Shell tool with
electro plated
diamond grits
for single
stroke honing.

Typically the shell tools have very long life, and this is achieved by the use of CBN or diamond abrasive. These tools have narrow lands to allow a very good flow of cutting fluid (Picture 15). Even parts with narrow lands, such as hydraulic valves, can be successfully honed with these tools

Single Stroke[®] honing is suited for industrial production of medium or large series, and it often is fully automated.

If the workpieces have been pre-machined very roughly, several honing operations may be necessary to get high accuracy. A combination of operations may be desirable: first with expanding honing tools for multi stroke honing, then with a single stroke honing tool. The most economical way is to do these several operations with a single chucking in multi spindle machines.

**Multi step or
combined
operations**

HONING MACHINES



◀ 28
More and more, six-axis
knee-action
robots are being
used for flexible
automation of
honing machines.

In mass production several operations can be done in one or several chuckings on complicated transfer lines. But the process-oriented ganging of several standard honing machines is usually the most economic solution for medium sized job lots. Here are a few handling systems:

- tool-specific handling systems
- linear robots (Cartesian systems)
- six-axis knee-action robots (Picture 28)

Most handling systems designed for just one type of workpiece move the workpiece to a definite place on the machine, where they are picked up by a gripper. But robot systems can use their own gripper to place the part on the tool, and they also remove the finished part after honing. This makes for accurate repeats, speed and flexibility. Together with the trend to smaller lot sizes this makes for more use of robots, even midsize lots. Following will be description and categorization of honing machines according to the size of production lots.

**Handling
systems for
medium large
job lots**

**Advantages
of robot
systems**

HONING MACHINES

Horizontal machines

Honing on horizontal machines with double-jointed holding fixture is basically limited by the stiffness of the workpiece. For honing long tubes machines are available with reciprocating spindle drives.

On the other hand, there is growing use of vertical machines with single-stroke® tools for honing relatively short, small holes, again with floating work-holding fixtures.

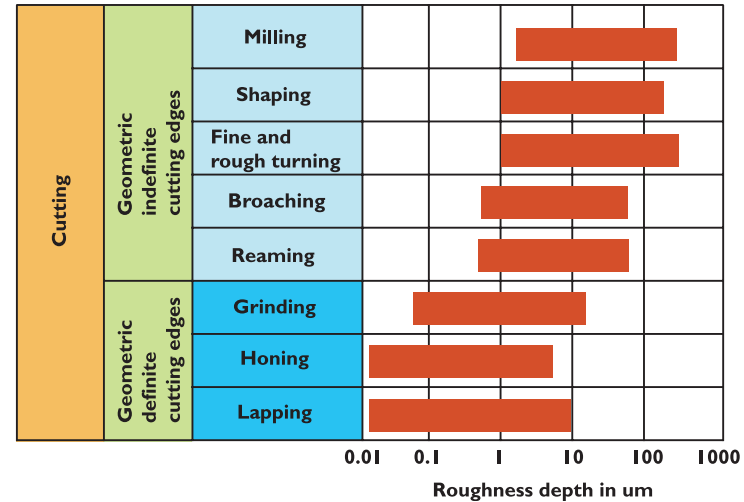


27 ▶
The double universal joint holding fixture of this horizontal honing machine allows the workpiece to float on the honing tool.

Size of job lot and automation

Only small lots are still loaded by hand. Modern automated honing machines are used more and more, and they may also be arranged in a row, and the total honing time is measured in seconds.

TECHNICAL BASICS



◀ 16
Achievable size accuracy and surface quality for different machining methods. (Source: Koenig, W., Klocke F.: Production Methods, Volume 2, VDI Publisher, Duesseldorf, 1996.)

Comparison with other high-accuracy machining methods

It is expensive to get geometric and surface accuracy with methods such as boring, grinding or fine boring.

The results and costs of the different methods are shown above (Picture 16). Grinding also creates a lot of thermal stress to the workpiece

Lapping creates comparatively low thermal stress. Fine and very fine operations can follow in the same operation. However the remaining loose abrasive grits can be a problem especially in complicated shapes of parts with small cross bores. Cleaning these parts thoroughly can be expensive.

Hardened steel can now be machined with geometric definite edge tools. For industrial use hard turning can be applied. The advantages of this method are short machining time, and it may be possible to work without cooling fluid.

Fine boring

Grinding

Broaching

Lapping

Hard turning

TECHNICAL BASICS

The hard turning method makes high demands on the stiffness of the tool. This increases with larger diameter-to-length ratio. High tool cost and heavy and expensive machines make the machining of long tubes costly. In addition, few machines are on the market, which can achieve accuracy and surface finish comparable to grinding. One exception would be combined turning/grinding centers, in which the workpiece in one chucking is hard turned and then dry finish ground.

Laser honing

Combination Laser Honing is a rarely used method, and it is for special applications in large series manufacturing. After honing a high energy laser ray will burn a fine structure into the surface. When this is required, the advantages outweigh the disadvantages of this method. If such a machine is not used continuously, it is an idle expense.

Shorter Processing Chains

The main advantage of honing is the combination of high stock removal rate with very high geometry and surface quality. Often pre-machining such as reaming, fine boring or internal grinding will be unnecessary. The further developments of systems, which are tuned to each other, consisting of machine, tool, abrasive and cutting fluid made it possible to eliminate the final lapping process and replace it with honing. Along with time saving came simplification.

Economics of honing technology

Honing saves costs because:

- better force application compared to internal grinding, fine and hard turning; this is especially true for long bores, since there is no deflection of the tool
- no danger of heat induced changes in microstructure of the material (as opposed to internal grinding)
- simpler and lower cost fixturing
- shorter cycle times
- lower cost of investments

HONING MACHINES

To feed up with ball bearing spindles or stepping motors are more accurate. These mechanical feed systems permit excellent control. They can be used with all available types of abrasive. Since the feed rate is programmable, numerically controlled machines have the following functions:

- automatic adjustment to the pre-selected work data after changing tools
- automatic micromillimeter-exact recalling and displaying the existing diameter
- rapid feed until honing tool touches the wall of the work-piece
- integrated control of stone wear
- optimizing stock removal rate by using suitable impulses

A condition for manufacturing high-accuracy bores by honing is the workpieces must not be distorted by chucking during the honing process. Depending on the type of work-piece, its weight and desired accuracy, the choice is between rigid, floating or universal-jointed holding. Often the choice for work holding is determined by the location of the bore axis. For instance, very large workpieces, such as cylinder blocks or pump bodies, due to their heavy weight or strong imbalance, must be held rigid.

Usually such work is done by a machine with a vertical spindle. These machines don't take up much space, and can be arranged in a row. The honing tool is held by a universal joint at the tool and a second universal joint at the drive shaft.

For light weight workpieces it is also possible to use a rigidly mounted vertical honing tool if the workpiece is held in a table which is double universal jointed.

Small lightweight workpieces are best honed on a horizontal machine. The workpiece is allowed to float on the honing tool. The holding fixture only keeps the part from rotating, but allows it to follow the tool. The centerline of the part is the same as the centerline of the tool. If the wall of the workpiece doesn't distort from chucking, this method is very accurate.

Feed systems

Tool installation and work axis

Vertical machines

HONING MACHINES

26 **▶**
Modern numerical controls integrate several functions, such as tool feed-up, size measurement, including even complex honing cycles.



Machine controls

To make this possible, flexible and easily programmed machines are popular. Modern numerical controls fulfill several functions in this respect (Picture 26).

NC functionality

Stone feed-up, measurements including the remaining stone life, the stroke activation with stroke position, the spindle drive, and even a tool changer can be integrated. In the case of multi-spindle machines there is also the ability to communicate between the various axes. Complete change-over, all with great ease for the operator, as well as reliable repetitive accuracy can be accomplished with numerical controls.

Feed systems

Numerical controls can also handle the necessary feed, size measurement, and corrections. This is done with air gages or mechanical gages. A size measurement at the start is followed by an in-process measurement during the honing operation. This determines the required feed-up for effective compensation for tool wear and microinches-accurate shut-off when the part is at finish size.

The type of feed system can have a decisive effect on the quality and cost effectiveness of multi-stroke honing. There are two basic tool feed systems - hydraulic or mechanical feed. Large machine usually employ hydraulic feed. The variable oil pressure is translated into proportional feed force. The feed-up is continuous.

Mechanical feed systems are used on small machines. The simplest way is spring force.

TOOLS AND WEAR

The flexibility of the honing system and cost effectiveness increases with the number of choices available (Picture 17). Therefore the manufacturers of honing systems take care to offer complete solutions. Not only the precision of the machine counts; it has to be used in conjunction with suitable tools and cutting fluids.

Today's industrial production uses continually expanding narrow-stone or full-circle or shell tools. In almost all cases the tools consist of several parts. Tools in an infinite variety are available to hone even difficult designs of workpieces and for honing all industrially used materials.



17 **◀**
The variety tool systems, suitable for varying applications.

But not only the correct choice of tool type and abrasive is decisive for the accuracy of the part, but the relationship of tool length and its overstroke and the honing fluid must also be considered. That's why it is important to consult a competent supplier.

The main criteria are:

- type of bore (open hole, blind hole, bores with keyway, tandem bores, etc.
- length of bore (short holes: less than five times bore diameter, long bores: more than five times diameter)

Tools and supplies

Types of tools

TOOLS AND WEAR

Stone length and overstroke

The correct length of the abrasive stone and the proper amount of overstroke have direct influence on the result of honing. A rule of thumb is the stone length should be about two thirds of the bore length, and the overstroke at the ends of the part should be about one third of the stone length. Too much overstroke can result in sharpening the honing stone for a greater length, and this reduced contact area increases the specific cutting pressure, which in turn removes more stock near the ends of the hole, resulting in bellmouth. Too short an overstroke will lead to barrel shape.



18

Single-stone miniature tool for diameters under 2 mm (0.080")

The increasing trend to miniaturization of workpieces, for instance in pneumatic and hydraulic systems has led to a corresponding miniaturization of honing tools. The market offers tool diameters down to the millimeter range. Components for fuel injection are an example. On the other extreme, honing tools up to 1000 mm (40 inches) in diameter are available for honing large engine cylinders.

Different diameters of the bores, as well as demands upon the rigidity of the tool require different designs of tools. For instance, honing tools for diameters less than 2 mm (0.080") will have no more than one honing stone, because of space limitation (Picture 18), or shaft or shell tools are used. In the case of very small diameters it is not possible to provide a feed system. In that case the tool must be pre-adjusted to the desired size. For larger diameters several different ways of adjusting the tool diameter are available.

HONING MACHINES

A large variety of honing machines and portable honing tools are available for mass production. There are many sizes and configurations on the market. The choice depends on factors such as size of the workpieces and the quantity of parts to be honed.

The market for honing machines can offer a practical solution for every case.

The machines can be single or multi-spindle, horizontal or vertical. The single-stroke system of honing is often done on multi-spindle machines.

Complex multi-spindle machines most often use a hydraulic drive. Standard machines with electro-mechanical drive are also available. On these machines the stroking movement is created by a crank or thread. The various machines on the market start with single-spindle machines, with manual feed-up of the tool and manual stroking of the workpiece. This type of honing machine is the most economical to use for repair shops, such as engine repair shops, as well as small-batch production. For industrial production of larger quantities of parts single- or multi-spindle machines are available, with a choice of semi- or fully automatic operation. Numeric control (NC) machines are also available.

The choice of machine depends not only on the requirements of each individual job, but mainly on the quantity of workpieces to be honed. These batch sizes are getting smaller, because of the great variety of technical components. This puts a premium on great flexibility, allowing easy switch-overs from one job to another.

Machine concepts

Hydraulic or electro-mechanical drive

The most suitable machine

TOOLS AND WEAR

Flushing

instance some tools are designed with a ring-shaped nozzle for the honing fluid. It is also possible to incorporate oil passages into the inside of the honing tool. This is especially valuable for blind hole work.

Lubrication

For materials which make long stringy chips the honing oil should have additional lubricating effect. High viscosity is desired there. These fluids are usually mineral or synthetic based. So far biological or water-soluble fluids are seldom used for honing; but for environmental reasons these fluids are gaining popularity.

Choice of honing fluid

There is a direct relationship between the viscosity of the fluid and the cutting ability of the honing stones. The choice of fluid has great effect on stone wear and honing time per part. It depends on many variables, such as material, abrasive, cutting speed and the amount of stock removal per part.

Since honing machines use a large amount of cutting fluid,



25

The honing process takes place with large area contact. The removal of chips and the cooling of the workpiece is done by special honing oils or emulsions.

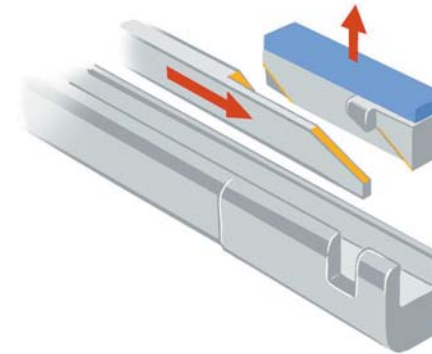
(Picture 25), it is not necessary to have cooling devices. Standard machines have their own tank for the cutting fluid, but is also possible to connect the machines to a central honing oil tank. Filtration is available by various systems, such as magnetic separators, paper or centrifuges.

TOOLS AND WEAR

In principle, the honing method determined the type of tool to be used. For multiple-stroke honing tools with narrow stones or with segments are used; the special requirements of single-stroke honing require tools of shell construction.

Tools for Multi-Stroke Honing

Except for very small diameters, classic multi-stroke honing uses single or multiple narrow stones. Diameters less than 1.0 mm (0.040") are honed with shaft or shell tools. They consist of a tube, slotted lengthwise, and in part armed with a layer of abrasive.



Usually narrow-stone tools

19
Feeding the stone out is done via a wedge or cone inside the tool.

The tool used for multi-stroke honing uses a wedge or cone inside the tool to increase the tool diameter during the honing process as needed to reach final size (Picture 19). Such feed-up can be mechanical, electro-mechanical or hydraulic. The accuracy of the feed system is a requirement for exact finish size of the workpieces. Tools for mass production often have further details, like cutting fluid supply through the inside of the tool, and an air gage system.

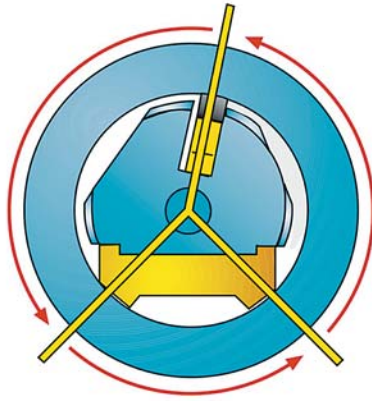
Feed-up during the honing operation

TOOLS AND WEAR

In both cases suitable jets are provided between the honing stones.

Asymmetric design of narrow-stone honing tool

The so-called asymmetric design has proven itself. Two guide shoes are so arranged that they are almost, but not quite directly opposed to the honing stone. This asymmetric arrangement (Picture 20) minimizes distortion of the tool and also guarantees automatic centering. The honing stone always touches the tightest part of the bore first. This creates roundness and straightness.



20 ►

The asymmetric arrangement minimizes tool distortion.

TOOLS AND WEAR

A harder abrasive grain does not necessarily make for greater sharpness of the grain, because the lesser total hardness of grain and bond causes wear and therefore an increase in the self-sharpening ability. This can be aided by occasionally reversing the rotation of the tool (only possible with symmetric design tools). Also the lesser hardness causes faster stock removal rates, because new sharp edges are constantly exposed to the material being honed. On the other hand, if too hard a bond is chosen, there will be the danger of the stone glazing. Grits will not break out, and the cutting action slows down. Especially when very fine surface finish is desired, the choice of the best stone is usually decided by several tries.

Superhard abrasives such as diamond or CBN are best for obtaining rough surfaces. The abrasive grits last a long time inside the bond. Only during contact will the abrasive grit lose the support of the bond, and potentially break out. Conventional honing stones are not self-sharpening, but the tool, because of its wear resistance, will retain size and geometric accuracy.

This is especially advantageous when honing very small diameters. It is also helpful for honing blind holes, where the usual dwell near the bottom may be unnecessary, reducing honing time. Especially helpful is the cost saving due to less downtime for changing tools. For mass production the use of diamond or CBN is most economical.

For the honing process the cutting fluid has to handle several jobs:

- Cool tool and workpiece
- Retain sharpness of the honing stone
- Flush chips and stone particles out of the hole
- Prevent seizure and welding inside the workpiece

In addition the cutting fluid must not discolor the workpiece (as in copper-based alloys). The fluid must also have a long shelf life, and it must be environmentally friendly.

Unlike grinding, during honing the workpiece is not subjected to severe heat stress. This is because the surface contact while honing is spread out over a large area. Multi-stroke honing causes even less heat stress than single-stroke honing. Honing fluid is used mainly to flush debris out of bore so it must be of low enough viscosity to act as a flushing medium. It also keeps the stones clean, so as to allow free cutting.

**New:
Microcrystalline
abrasives**

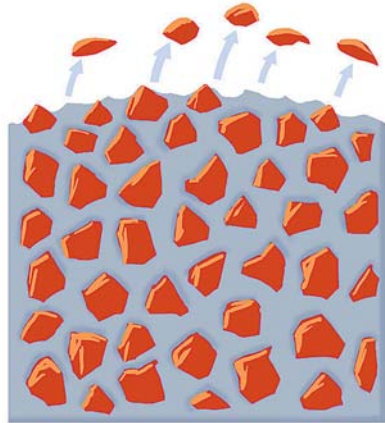
**Superhard
materials**

**High accuracy
for size and
geometry**

Honing fluids

Flushing

TOOLS AND WEAR



24 ▶

Each grit should break out of the bond at the exact moment when it got too dull to cut.

Criteria for abrasive bodies

Stones for multiple stroke honing consist of several layers of abrasive grits, bonded together to form an abrasive stick. Each one of the grits acts as a chip removing tool. Once the particular grit is worn down and too dull to cut, it will break out of the bond (Picture 24).

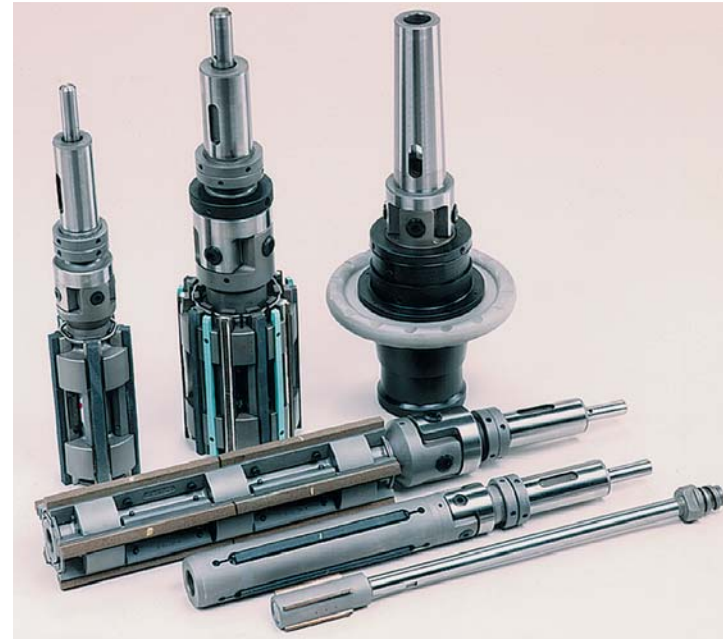
Hardness and toughness to last a given time,

Honing stones, specifically the abrasive grains and the bond have to fill the following criteria:

- high resistance to changes in temperature, to withstand the extreme temperature during honing and the rapid change of temperature
- chemical inertness, to avoid any chemical reactions with the material being honed or with the cutting fluid, considering the high temperatures generated at the microscopic point of attack of each grit.

Desire for synthetic materials

Natural abrasives, such as quartz, corundum, sand and natural diamond are in very limited use, because its properties can not be reproduced. The synthetic abrasives include aluminum oxide, silicon carbide cubic boron nitride (CBN), and synthetic diamond. The main advantage of CBN and synthetic diamond is their hardness. In addition new developments in the structure of these two superabrasives have resulted in a second generation, microcrystalline abrasives, which don't have to break completely out of the bond when needed, but they can fracture and thus offer new cutting edges. This increases their useful life.



◀ 21

Segment tool have the advantage of large area of abrasive contact, and therefore are well suited for honing bores with interruptions in the cylinder wall.

Multi-stone tools have several honing stones, arranged parallel to each other. If the stones are arranged evenly around the circumference of the tool, these tools are called Segment tools (Picture 21). They have the advantage of large stone contact area and little likelihood of material transfer to the end zones or to interruptions in the wall of the workpiece.

Multi-stone tools

TOOLS AND WEAR

Specialized high-performance tools

Tools for Single-Stroke® Honing

Single-stroke® honing is used more and more. These tools have demands quite different from multi-stroke tools. The large area of contact creates good honing results, especially for holes with interruptions in the circumference, but they also cause more heat than multi-stroke tools. The quality of the cutting fluid has to accommodate this.

Size adjustment before honing

Since the entire amount of material has to be removed in one single stroke, the tool has to be adjusted to the final diameter, and this has to be done before honing. This creates advantages for the repetitive finish size, which in multi-stroke honing could only be achieved through extreme accuracy of the shut-off. To get large number of workpieces with very little downtime, the life of the abrasive has to be very long, from 1000 to more than 200,000 parts.



22

With especially rigid shell tools the most accurate honing operation can be done in one single stroke.

Shell tools

The demands listed above can be fulfilled with modern shell tools (Picture 22). They consist of a sleeve that has an angled slot through its entire length, the outside of which has been covered with an electro plated layer of abrasive grains.

This abrasive is usually diamond or CBN. Feed-up occurs via a taper on the inside of the tool. This type of tool is called a single-stroke® honing tool and is the most economical method for sizing small parts for fuel injectors, micro technology and fine machine technology.

TOOLS AND WEAR



23

Conventional and super-hard abrasive tools

The choice of tool is important for the success of a manufacturing job, as the method of machining, the cutting fluid, and, not least, the abrasive material. Abrasives are available in many varieties of grit type, grit size, bond, hardness, and impregnation (Picture 23). Similar to classic grinding methods, the abrasives are categorized as conventional and superabrasives.

Honing tools can be loaded with a variety of stones. Depending on the job requirement, resin bond, ceramic bond, or metal bond may fill the need for strength, connective strength, and life expectancy of the honing stone.

Abrasive materials