Innovative flat honing with vitrified-bond grinding and conditioning tools

The flat honing process has long been established for the high-precision machining of ceramic, metal and polymer components when the very highest degrees of plane-parallelism are required [1]. Unlike with grinding in which there is an increasing trend towards high-speed grinding processes [2], such as for example external cylindrical, peel grinding and deep grinding where the contact between the tool and the grinding body is primarily linear, with flat honing the surfaces that are being machined are in almost 100% contact with the tool. Despite the lower cutting speeds, this results in high material rates characterised by a low thermal load and little warping of the components. Due to the characteristic planetary kinematics there are different loads on the individual abrasive grits, with a resulting wear pattern as a function of the disc pitch. This must always be taken into consideration in the design of the tool, of the machine, in application and also when conditioning. This article by **P. Beyer** and **M. v. Ravenzwaaij.**

The ever-increasing demands on components in terms of dimensional, geometric and positional tolerances, and also the objective of reducing costs through continuous process improvement, can be met only through close cooperation between the tool manufacturer and the machine builder. With flat honing, new systems are increasingly enabling further increases in material removal rates to be achieved through faster cutting speeds.

This article describes the optimising of a flat honing system, also called 'Clean lapping with planetary kinematics' [1], with which today virtually any material, from soft plastic through (sintered) metals and ceramics to high-strength PCD composites, can be machined in a reliable process using suitable grinding and conditioning tools.

The state of the art

The twin-disc principle of the lapping process with planetary kinematics (loose abrasive grit) has been established for a long time. Conventional machines used in this area have a so-called C-frame construction. Because of the use of oils and unbonded lapping pastes the process is relatively cleaning-intensive, which is critical both with regard tocost per part as with regard to possible disposal problems.

The introduction of tools with bonded abrasive, e.g. diamond or cubic boron nitride (CBN), is therefore to be seen as a major innovation for the development of the process generally.

The first applications involved the use of grinding tools with resin and metal bonds. However, the process forces resulting from the large contact areas with the parts led to many difficulties with both the machine and the process. As only few changes were made to the machines parameters and control systems to make them specifically suitable for flat honing, very little progress was made for a long time.

It was only with the use of vitrified-bond tools that significant progress was made compared with conventional lapping methods [3]. A further step forward was in tool design in the form of individual pellets, which as well as the concentration calibrates the number of cutting edges engaging the workpiece due to the pattern with which a wheel is covered. For a long time however relatively little development work has been carried out on the vitrified bond of the CBN and the diamond itself. Generally, existing systems of other processes were just slightly modified and adapted.

Furthermore, until now the conditioning of the grinding tools has not been a very reliable process. The usual process for sharpening diamond wheels for example is the use of soft corundum stones [4], SiC rings mounted on the rotor discs, or loose abrasive. All these methods require a great deal of experience, take a long time and because of the fact that they depend on the operator's skills, they are only reliable to a limited extent.

The basic principle of the workpiece/tool arrangement and also the relative movement between the two due to the planetary kinematics are shown in Fig 1a and Fig 1b. The wear patterns that are produced on the tool as a result of this are shown schematically in Fig 2.

The limit of any process is determined by the weakest link in the chain. An innovative improvement in the process is therefore only possible with a new design of the system as a whole, which can only be successful with coordinated development both of the machine and the tool.

Machine development

Any new machine concept must take the following basic factors into account:

- a stable torsionally stiff machine concept
- a wide range over which the cutting speed can be varied
- it must be possible to adapt (increase) the force that can be applied to the workpiece materials

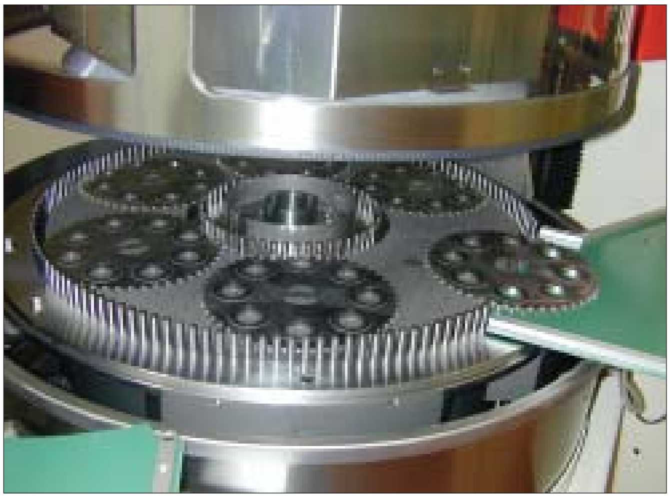

Fig 1a Arrangement of the machining area of a flat honing machine

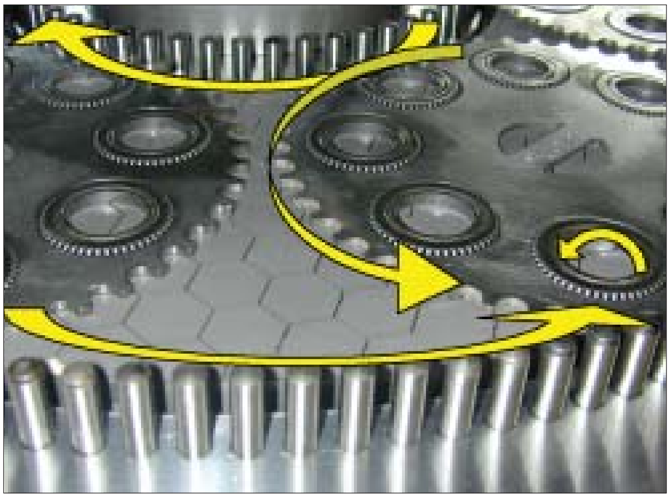

Fig 1b Planetary kinematics in flat honing

The main design difference compared with existing systems is the bridge design, which may be regarded as the ideal design, used in the new DLM 05 series (DLM 705, DLM 1005, DLM 1505). In the balance beam systems hitherto (with or without a swivelling head), the bearing area was one weak point of the C-frame construction. The bridge-type design does not have this disadvantage. The structure optimised with this type of design enables machining forces of up to four tonnes to be involved. Other design improvements include uncoupling all the motors from the drive shafts, i.e. any deformation that might occur no longer depends on the power, a speed increased to 400 rpm (in current tests this is even up to 2000 rpm), and much improved accessibility for the operator. With this, the key machining parameters as contact pressure and cutting speed, in relation to stock removal, can be selected to specifically suit the workpiece material and the workpiece.

A summary of the technical parameters that are available is given in Table 1. These provide the essential conditions for the development of flat honing or fine grinding with planetary kinematics.

In combination with the latest developments in tooling, such as HPB technology [5], from now on the weakest link in the chain is the workpiece itself, or the rotor disc (template) in which the workpiece is guided.

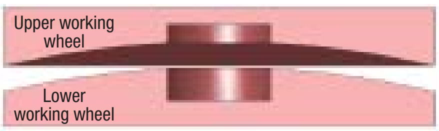

Fig 2 Possible wear pattern on tools for flat honing

Fig 3 The Stähli DLM 705

Tool development

As well as the basic design of the machine, the process is largely determined by the selection of suitable grinding/honing and conditioning tools. Because of their advantages that are specific to the system, when designing high-performance grinding or honing processes it is preferable to use vitrified bonds for the CBN and diamond abrasives. The main advantages are the very free-cutting topography of the grinding tool, the low contact pressure that is needed as a result and the very short machining times that are possible while

	DLM 705	DLM 1005	DLM 1505
Outer ∅ of the working wheels	500 - 720 mm	800 - 1250 mm	1300 - 1600 mm
Number of rotor discs	4 - 7		
Distance between the working wheels	<390 mm		
Workpiece load, stepless	0-2000 (4000) daN	0-3500 (6000) daN	0-4000 (8000) daN
Numeric control	Free programmable		
Cut off accuracy	0.1 µm		
Cooling of the working wheels	Yes		
Speeds of the upper and lower working wheels, stepless			
Flat honing and fine grinding	0-200 (400) min^{-1}	10-240 (15-350) min^{-1}	6-150 (10-200) min^{-1}
Centre drive	0-100 (200) min^{-1}	5-120 (7-180) min^{-1}	4-80 (5-100) min^{-1}
Rotational direction of the drives	Free programmable		
Performance			
Power	22 (39) KW	40 (61) KW	61 (97) KW
Dimensions, incl. protective hood W x D x H	approx. 1900x1700x2600 mm	approx. 2600x2100x2620 mm	approx. 3100x2800x2720 mm
Weight	approx. 7,800 kg	approx. 12,500 kg	approx. 19,500 kg
Options			
Semi and full automation, robot loading, linking	Yes		
Connection to precision brushing machine	Yes		

Table 1 Technical data on the 05 series

also achieving an excellent geometry on the workpiece. A summary of the technical fundamentals of vitrified-bond tools can be found in reference [5]. Below we will deal only with the adjustments that are specific to flat honing.

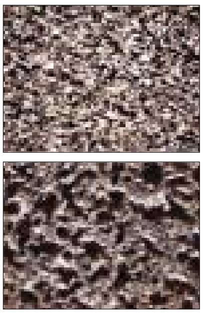

Fig 4
Top: Standard structure, grit size 230 mesh
Bottom: Highly porous structure with defined pore radius distribution, grit size 230 mesh

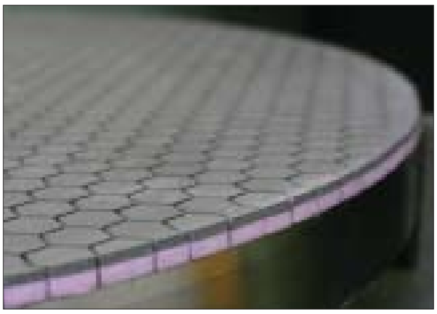

Fig 5 Composite technology vitrified-bond CBN wheel

Fig 6 Technical design to stabilise the edge zone of a CBN/diamond wheel for flat honing (schematic) – goldfish pellets

Grinding wheel specifications

Due to the large contact surfaces, in order to achieve a high material removal rate generally a relatively low CBN/diamond concentration in the range C50-C75 should be chosen with as porous a structure as possible. The wide range of options for adjusting the parameters of abrasive concentration, pore volume and pore radius distribution is available only with vitrified bonds. The porous structure ensures the supply of coolant and chip removal and can be adjusted with regard to pore volume and pore radius distribution (Fig 4).

Due to the large contact surfaces and the large amount of chips that are produced in flat honing, this function is also determined, or helped, by the distance between the pellets, which are usually hexagonal. As the abrasive layer is increasingly worn away, due to the reducing depth of the gap the layer is worn away almost entirely. To avoid this negative effect the pellets can be provided with a vitrified substrate (blind layer) (Fig 5).

Composite tool technology

These structures, called composite tools or pellets, are produced economically by a combined pressing of the abrasive and the blind layer. Due to the nature of the ceramic manufacturing process, the blind layer must be adapted to the thermal and physical properties of the abrasive layer so that in the consolidating firing process they are sintered such that they are free of stresses. The factors of grit size and concentration, coefficient of thermal expansion and sintering shrinkage must be adjusted accordingly.

Design details

In order to optimise the grinding wheel for a more reliable running-in of the workpiece components, the fringe area of the wheels has been redesigned to prevent there being too many gaps at the edge of the wheel, the external and the internal diameter are coated with double pellets, so-called 'goldfish pellets' (Fig 6).

Dressing/conditioning tools

In order to optimise the entire grinding process on the tooling side, it is a matter for discussion as to whether new approaches are possible in the selection of the conditioning tool that in terms of quality and the time needed can shorten the lengthy setting process. As well as the levelling of CBN abrasive layers, above all the problems involved in the reconditioning of diamond tools have so far not been resolved very satisfactorily.

The basic approach for designing new dressing tools as far as the bond is concerned is that of vDD technology (vitrified Diamond Dresser), namely vitrified-bond diamond tools [6]. The known advantages in terms of lower dressing forces, efficient 'free-cutting' conditioning and excellent grinding wheel levelling make these tools ideal for the conditioning of grinding wheels with a large surface area for flat honing.

A corresponding design is shown in Fig 7, and in use in Fig 8. The conditioning tools, mounted on rotor discs, rotate and are moved over the surface of the grinding tool to match the flow of parts.

Application examples

The latest technical developments on the user side are leading increasingly to the use of new and usually hard-to-cut materials. Because their composition is largely independent of metallurgical

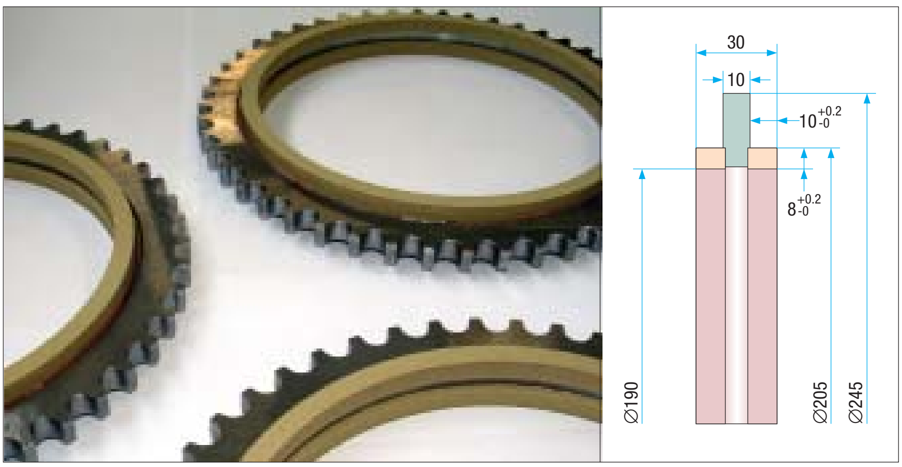

Fig 7 vDD dressers of specification D11-120-P-8-280-X150-V86-39-2

Fig 8 Dressing and sharpening ring in use

processes, sintered metals have increased considerably in importance both in terms of the materials and the manufacturing process. The method by which they are produced does however result in a hardness gradient of the material, which affects cuttability. Machining strategies to date have therefore required a two-stage process involving a turning operation that is carried out beforehand.

A machining process consisting solely of grinding has until now been hindered due to the rapid loss of a tool's free-cutting properties and the consequent need for frequent sharpening, or the wear on the tool with a loss of the geometry of the grinding wheel.

As a result this also had an adverse effect on the vibration behaviour of the machine, which meant that it was not possible to produce the workpieces within the required dimensional tolerances.

In the example described (1), with modern flat honing technology this machining can be reduced to a reliable single-stage process.

With the use of HPB grinding tool technology on the new DLM 705 this can be improved significantly. Shorter and more constant machining times with better quality, much longer periods between conditioning and reduced burr formation guarantee a production process that is productive and reliable.

Another application example (2) for the machining of 100 Cr 6 components for an optimised process of machine, machining tool and conditioning wheel confirms the optimum design of the entire concept by the machine manufacturer and the tool supplier.

Application example 1: Combination Stähli DLM 705, Meister HPB Vit-CBN and vDD technology		
Application	Flat honing on Stähli DLM 705 with oil	
Material	Sintered steel D	
Allowance	0.3 mm or 300 µm	
Number of parts/load	6 rotor discs with 10 parts = 60 parts	
Coating	19%	
Honing tool	Swiss Master HPB Vit-CBN CB56-170-P-11-215-X75-V51-31	
Dressing tool and sharpening tool	Swiss Master vDD D11-120-P-8-280-X150-V86-39-2	
Results	**Swiss Master HPB Vit-CBN**	**Standard**
◆ **machining time/load**	2 min	3 - 7 min
◆ **machining time/workpiece**	2 s	3 -7 s
◆ **dimensional stability**	± 1 µm	± 2 µm
◆ **R_z**	2 - 3 µm	2 -3 µm
◆ **flatness**	0.5 µm	1 -1.5 µm
Dressing interval	after assembly 30 s	once a day 60 s
Sharpening interval	once a day 20 s	2 – 3 times per shift 60 s (with > 7 mins machining time)
Application example 2: Combination Stähli DLM 705, Meister Vit-CBN and vDD technology		
Application	lat honing on Stähli DLM 705 with oil	
Material	100 Cr 6	
Allowance	0.2 mm or 200 µm	
Number of parts/load	6 rotor discs with 390 parts = 2340 parts	
Honing tool	Swiss Master HPB Vit-CBN CB56-1450-P-9-260-50-V51-32	
Dressing tool and sharpening tool	Swiss Master vDD D11-120-P-8-280-X150-V86-39-2	
Results	**Swiss Master HPB Vit-CBN**	**Standard**
◆ **machining time/load**	2.5 min	2.5 - 7 min
◆ **machining time/workpiece**	0.065 s	0.065 - 0.18 s
◆ **dimensional stability**	± 1.5 µm	± 3 µm
◆ **R_z**	0.6 - 0.8 µm	0.8 - 2.5 µm
Dressing interval	after assembly 30 s	after assembly 60 s
Sharpening interval	after approx. 150,000 parts	after approx. 100,000 parts

Prospects

The general trend in favour of vitrified-bond high-performance tools should continue in the area of flat honing as well, not least due to the machine concepts which are now much more suitable. In future, the combination of vDD technology with the conditioning of vitrified-bond diamond tools for the flat honing of, for example, ceramics, will also be the subject of detailed tests.

The application examples that have been described show clearly that it is only through close cooperation between the machine builder and the tool supplier that the total machining system can be fully optimised. Both innovative machine concepts and also new approaches in the areas of tool development, carried out in close coordination one with the other, enable the user to increase productivity significantly. ◆

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