DEVELOPMENT OF A HIGH-SPEED-DEBURRING TOOL

Prof. Dr.-Ing. habil. Hans-Michael Beier
FHTW Berlin
Berlin, Germany
dr.beier@beier-entgrattechnik.de

Dipl.-Ing. Reinhard Nothnagel
Dr. Beier-Entgrattechnik
Altlandsberg, Brandenburg, Germany
r.nothnagel@beier-entgrattechnik.de

ABSTRACT

Systems for the deburring of workpieces with inner edges generally have cutting edges supported by springs or spring-like components. Due to this feature, usable rotation speeds and feedrates are relatively low – the longer time for deburring results in higher production costs.

The development of deburring tools without spring elements for machining inner and outer edges leads to faster processing. In this case, the forces at the cutting edges are controlled by the pressure of a liquid or gaseous media – in the most cases the cooling media - instead of spring forces. Thusly, rotation speed and feed can be increased considerably, and high-speed deburring (HSD) is possible.

Through the variation of media pressure, rotation speed, and feed, the resulting quality can be controlled and optimized. The surface of the workpiece is not influenced negatively by the deburring process – modifications of the tool construction can prevent surface quality deterioration.

INTRODUCTION

Burr elimination and minimization are gaining increased importance in industry and research. Therefore, efforts in the field of deburring have been intensified lately. Due to increasing costs and higher quality requirements in manufacturing, the need for deburring procedures that are fast and of high quality, at reasonable costs.

Components in which liquids play an important role as coolants and/or lubricants, for example, internal combustion engines and transmissions, are expected to have long maintenance intervals. Therefore, they are faced with increasing demands on purity and residues of foreign matter originating from the usually complicated production process. In addition, there are higher constructional requirements associated with edge quality. This tendency can be exemplified by the specification of an edge with $R \leq 0.1$ mm in a difficult to access area of the workpiece.

New principles for tools and processes in the field of deburring have seen slow development. Correlations exist between the following aspects:

- predefined function of the component
- work material
- burr minimization
- deburring methods and tools, and
- quality requirements of the deburring operations.

However, they have not been studied sufficiently for the design of deburring processes. Many companies lack a deburring specialist. Expectations are high and pressure is exerted on consultants, developers, and manufacturers of deburring processes. Nonetheless, there won't be a universal deburring process in the future.

Since the mid-eighties, efforts have focused on the design of a non-rigid bearing for deburring tools. This design consists of guiding a geometrical cutting edge in two planes and, in the third dimension, supporting it by an elastic bearing by means of a spring or an elastic support (rubber). Guiding the tool in the two planes ensures power transmission, the third plane ensures elasticity within certain limits.

The new deburring tool developed by the company Dr. Beier-Entgrattechnik goes one step further. In the case of this tool, the elasticity in the third plane is accomplished by a gaseous or liquid medium. The cutting edges of the deburring tool are directly driven by the medium.

THE FUNDAMENTAL PROBLEM OF DEBURRING

When examining the customary deburring methods with regard to their quality and the expectations of the user, one can perceive a contradiction: there is no ideal deburring method. The reason for this lies within the system itself. The following factors have a great impact on the deburring result:

- The deburring result is considerably influenced by the properties of the material at the burr base, i.e. the existence of other elements such as graphite, or intermetallic transitions at the grain boundaries, that can weaken or strengthen the material. Furthermore the workpieces are made of various materials. The properties of the material are spreading over a wide range (from GJL to Al and on to high-alloy steel).

- The tolerance of the edges to be deburred (from the unmachined part to the finished part).

- The preceding manufacturing stages with their different mechanisms of burr formation (resulting in casting burrs, grinding burrs, different burr morphologies, e.g. needle-shaped burrs, knife burrs, etc.).

- The constructive design of the workpiece to be deburred. There is no ideal shape for deburring. A design suitable for deburring is only possible in individual cases. There is, however, a certain prioritization of basic shapes which are easy or less easy to deburr, at least for shapes located on the outside, such as a circular entry into a bore or shaft end.
- Reduction of errors inherent to the main production technology (e.g. boring, milling, etc.).

Deburring of Intersecting Bores

Deburring of intersecting bores is a highly difficult task that is influenced by the following circumstances:

- The burr base profile to be deburred is an ellipse lying in space.

- This ellipse cannot be assigned any geometric base plane.

- The edge angle is not constant.

- The tolerance of the two intersecting bores results in an undefined orientation - within certain limits - of the burr base of the ellipse.

- If effective drilling methods (e.g. deep-hole drilling) are applied, the problem caused by the possibly increased tolerance of the center of the bore hole becomes more critical.

- Drill wear affects the amount of developing burr.

- Burr size changes greatly from one part of the workpiece to another. In general, exit burrs are much larger than entrance burrs.

- Drilling of a cross-hole results in considerable amounts of chips in the intersecting hole

Thusly, burr orientation and dimension are not constant neither in time nor location!

Deburring of Hole Intersections by Producing a Defined Edge

There are many deburring methods for deburring outer edges. However, if a defined edge with a radius or chamfer of 0.1 mm or less is demanded, there is no suitable deburring method that fulfills this requirement.

STATE OF THE ART

The companies Cogsdill, Heule and Dr. Beier-Entgrattechnik have developed tools to deburr hole edges and intersecting borings. When deburring transversal holes, two different methods are used.

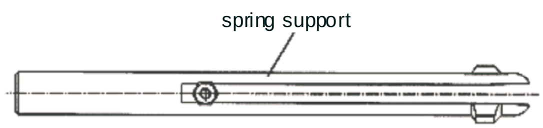
The deburring tools from Cogsdill and Heule enter the cross-hole in one sense of rotation, deburr the cross-hole and then turn back in the same sense of rotation. The tools from Dr. Beier-Entgrattechnik enter the main bore - where the burr is located - with a right-hand rotation and reverse with a left-hand rotation. All hole intersections in the main bore are deburred.

Being elastically supported, the cutting edges are pressed into the tool shank when the tool is driven through the cross-hole. In practice, four fundamental principles describe the elastic bearing of geometrically defined cutting edges:

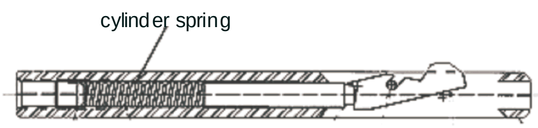
- Support fixed at one end, e.g. Cogsdill's "Burr-Off" deburring tool (Figure 1a).
- Axially arranged cylinder spring with indirect power transmission, e.g. Cogsdill's "Burraway" deburring tool (Figure 1b).
- Axially arranged spiral spring with direct power transmission, e.g. Heule's "Cofa" tool (Figure 1c).
- Elastic support having a direct effect radially/axially, e.g. Dr. Beier-Entgrattechnik's "Gummientgratwerkzeug" rubber deburring tool (Figure 1d).

The elastic supports of these tools present the following disadvantages:

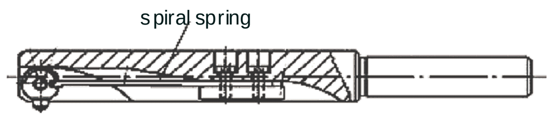
1. The deburring speed is limited by the inertia of the spring components.
2. It is impossible to change the tension force of the spring components or the compliance of the elastic support during the deburring operation. When the tool is driven through the boring (the cutting edge is folded into the tool shank) the load is even higher, so there is a risk of altering the surface roughness or of leaving traces on the bore surface.
3. When using a support fixed at one end ("Burr-Off" tool), there is a compromise relationship between the force necessary for detaching the chip and the admissible tension at the clamping end.
4. The indirectly operating cylinder spring ("Burraway" tool) transmits the errors from the elastic modulus and the shear modulus of the spring and generate friction.
5. The spiral spring that operates directly ("Cofa" tool) presents the variations of the elastic modulus of the spring.
6. The number of revolutions and so the speed cannot be varied or increased in a wide range to keep the function of the tools.
7. In the case of the deburring tools by Cogsdill and Heule, deburring at a single sense of rotation presents the danger of producing a secondary burr.



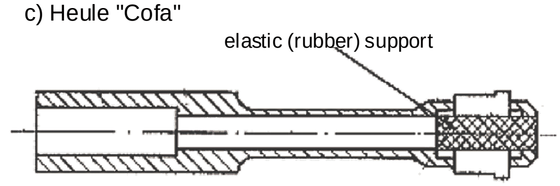
a) Cogsdill "Burr-Off"



b) Cogsdill "Burraway"



c) Heule "Cofa"



d) Beier-Entgrattechnik "Rubber tool"

FIGURE 1. CONVENTIONAL DEBURRING TOOLS BY COGSDILL, HEULE, AND BEIER.

DESIGN OF THE FLEXIBLE CUTTING EDGES OPERATED BY DIRECT CONTROL

Figure 2 shows the deburring tool operated by direct control. It consists of a base body (tool shank), one or more cutting edges, with compliant bearing at the opening of the preliminary deburrer. The cutting edges lie loosely on the supporting body with a certain amount of play and are pushed outside by a medium, e.g. air or drilling oil under pressure, which is pressed into the through boring of the base body (Figure 3).

Hydraulic control of the medium enables the deburring tool to “drive out” the cutting edges exactly at the hole intersection in order to remove the burr. It is an advantage that the cutting forces can be adjusted to the changing dimensions of the burr in the course of the machining and to different materials.

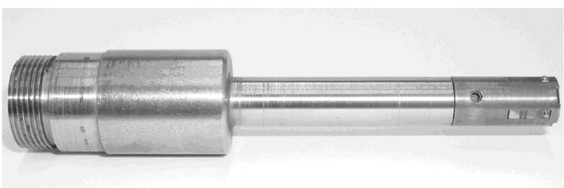
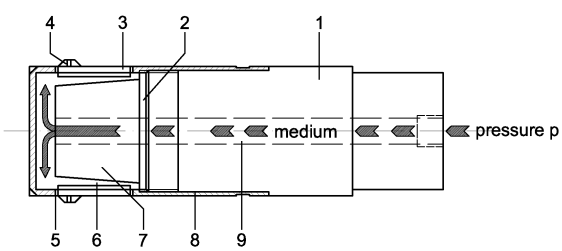


FIGURE 2. EXAMINED DEBURRING TOOL.



1 Tool shank, 2 End of shank, 3 Cutting edge body, 4 Cutting edge, 5 Opening, 6 Play, 7 Supporting body, 8 Shaft piece, 9 Through boring

FIGURE 3. SCHEMATIC PRESENTATION OF THE DEBURRING TOOL.

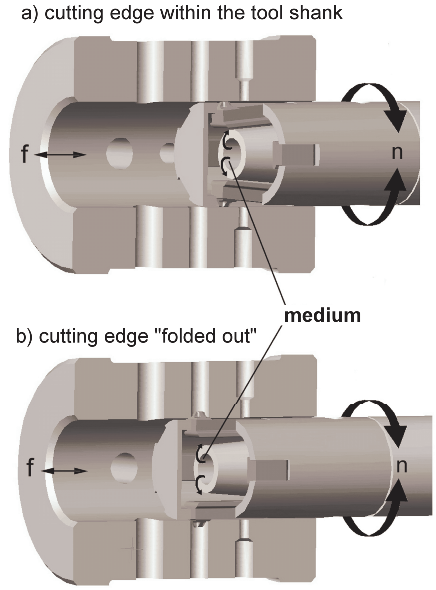


FIGURE 4. SCHEMATIC PRESENTATION OF THE MODE OF OPERATION OF THE DEBURRING TOOL OPERATED BY DIRECT CONTROL.

The direct-control, flexible deburring tool, like the rubber deburring tool, enters the main bore with a right-hand rotation and pulls back with a left-hand rotation, thus deburring the edge of the main bore as well as all transversal holes in a single operation (Figure 4).

TEST RESULTS OF THE FLEXIBLE DEBURRING TOOL OPERATED BY DIRECT CONTROL

Various tests were carried out using the flexible deburring tool operated by direct control. The following points were examined in particular:

1. Deburring quality and speed of cross-holes with diameters from 1 mm to 8 mm, and intersecting main bore with a diameter of 9.8 mm.

2. Surface roughness of the main bore.

3. Production of a defined edge when deburring the edge of the cross-holes, with and without an axial feed during operation.

AW-AlCu4PbMgMn, 9S20k, C15, 42CrMo4, and X5CrNi18-10 work materials were used for the tests. Air was used as the medium to control the cutting edges.

Cross-hole Deburring Tests Results

In the experiments, the deburring tool enters the main bore of the workpiece under pressure, in right-hand rotation. Having gone through the main bore, the feed is stopped and the rotation of the test body (lathe) is changed into left-hand rotation. After this, the deburring tool is withdrawn out of the main bore.

Table 1 shows the materials of the workpieces and the parameters of the deburring tests and their range. Tests were carried out at rotational speeds from 800 to 2000 1/min, feedrates from 0.106 to 0.608 mm/rev, and at pressures ranging from 4 to 10 bar. The cross-holes were completely deburred under all testing parameters.

TABLE 1. PARAMETERS AT DEBURRING TESTS

Material	Range of rotation [1/min]	Range of feed [mm/r]	Range of pressure p [bar]
Al-alloy	1000 - 2000	0.244 – 0.608	4
9S20K	1000 – 2000	0.244 – 0.608	6 – 8
C15	1000 – 2000	0.244 – 0.608	6 – 8
42CrMo4	1000 – 2000	0.244 – 0.608	8
X5CrNi18-10	600 - 2000	0.106 – 0.608	8 – 10

It turned out that the characteristic of the edge can be influenced by the choice of parameters. The edge can be more chamfered by increasing the pressure at constant feed, reducing the feed at constant pressure or changing both parameters. Otherwise the edge can be less chamfered by reducing the pressure at constant feed, increasing the feed at constant pressure or varying both.

It was determined that characteristic of the edge is mostly influenced by the feed. Figure 7 shows examples of different forms of edges, numbers 1-3 showing edges which are more chamfered, and numbers 4-6, edges which are less chamfered (The edges are not specified more by measurement).

The chamfers can be measured by the projected width using cross sections (ref. Tables 2-5).

Influence of the Deburring Tool on the Surface Roughness of the Bores

In order to recognize a change in the surface roughness of the main bore caused by the deburring tool, the surface roughnesses R_a and R_z of the main bore were measured before and after the deburring tests.

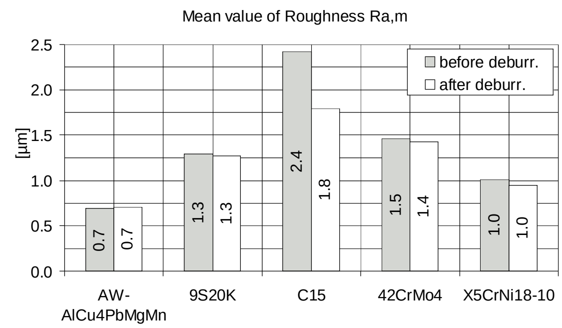


FIGURE 5. MEAN PEAK-TO-VALLEY HEIGHT $R_{A,M}$ BEFORE AND AFTER DEBURRING.

Peak-to-valley heights $R_{a,m}$ and $R_{z,m}$ show that the surface roughnesses hardly changed after deburring. In the case of very rough surfaces, the roughness is reduced considerably in some instances (smoothing effect). The deburring tool had hardly any influence on the surface quality of the main bore. The mean peak-to-valley heights $R_{a,m}$ and $R_{z,m}$ of the tests are presented in Figures 5 and 6.

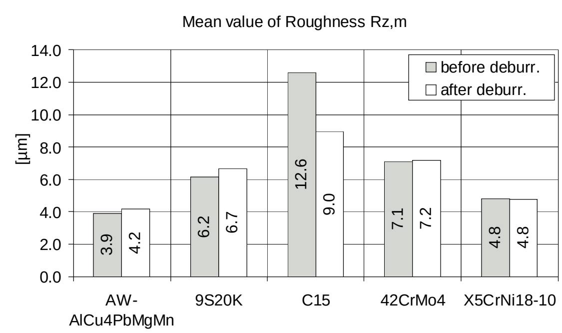


FIGURE 6. MEAN PEAK-TO-VALLEY HEIGHT $R_{Z,M}$ BEFORE AND AFTER DEBURRING.

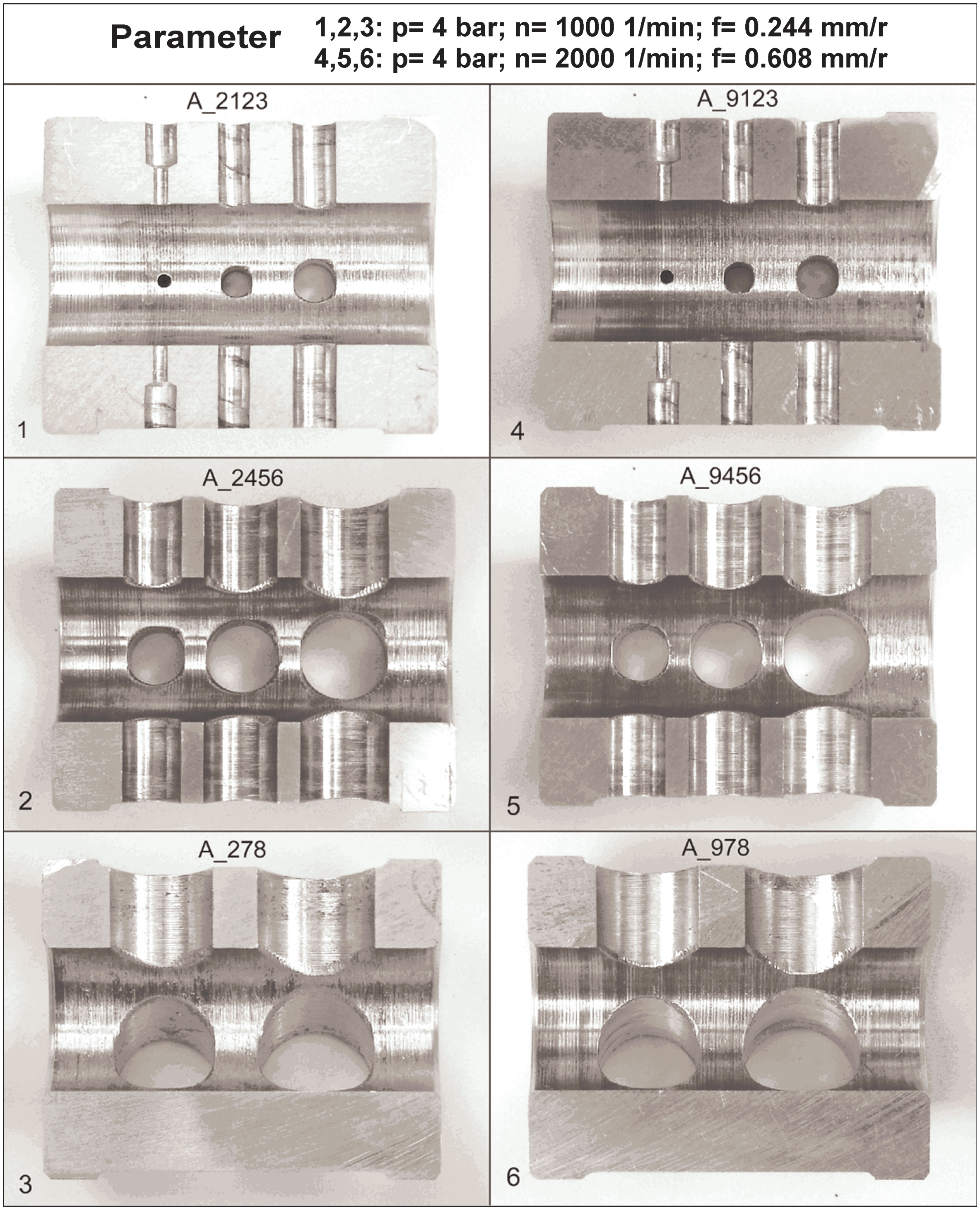


FIGURE 7. EXAMPLES OF CHAMFERED EDGES, SHOWING AW-AlCu4PbMgMn TEST BODIES AFTER DEBURRING.

PRODUCTION OF A DEFINED EDGE

With axial feed during operation. It was established that the edge of the main bore (entry of tool into the bore) was deburred. The shape of the deburred edges resembles the shape of a chamfer (Table 2 and 3) or also in some instances a rounding. By increasing the feed, the dimensions of the edge are reduced. After deburring, the resulting chamfers had dimensions of 0.07 mm to 0.46 mm at an edge angle between 27° to 62°, depending on the feed and material. Tables 2 and 3 show Al and CrNi as examples of the distinctive shape of deburred edges.

Without axial feed during operation. The tests showed that it is possible, with all materials, to reach a distinctive shape like a chamfer with the deburring tool. The dimensions of the produced edges without axial feed were between 0.23 mm and 0.5 mm and at an edge angle between 45° and 64° (Tables 4 and 5). The angle of the chamfer or the radius depends on the geometry of the cutting edge. Tables 4 and 5 show Al and CrNi as examples of the produced edges.

TABLE 2. TESTING RESULTS WITH AXIAL FEED, MATERIAL AL-ALLOY.

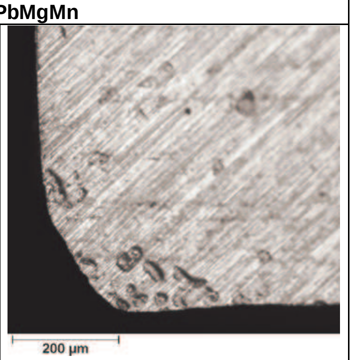
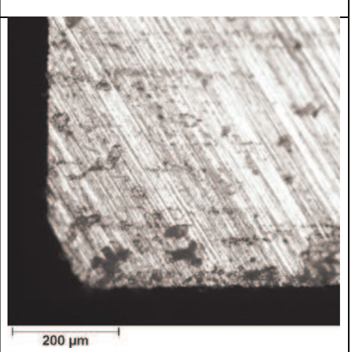
Material AW-AlCu4PbMgMn		
rotational speed [1/min]	1000	
pressure [bar]	4	
feed [mm/r]	0.244	
Projected width of edges [mm] 0.14 x 0.24; ca. 56°		
rotational speed [1/min]	2000	
pressure [bar]	4	
feed [mm/r]	0.608	
Projected width of edges [mm] 0.07 x 0.13; ca. 62°		

TABLE 3. TESTING RESULTS WITH AXIAL FEED, MATERIAL X5CrNi18-10.

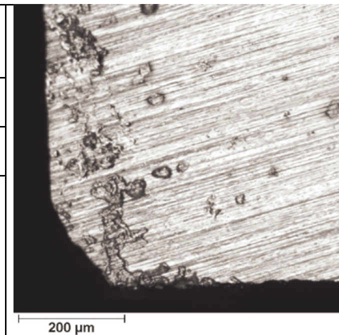
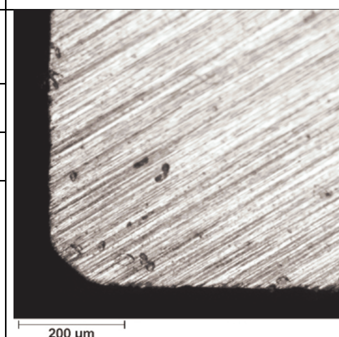
Material X5CrNi18-10		
rotational speed [1/min]	1000	
pressure [bar]	8	
feed [mm/r]	0.244	
Projected width of edges [mm] 0.11 x 0.17 ; ca. 55°		
rotational speed [1/min]	2000	
pressure [bar]	8	
feed [mm/r]	0.425	
Projected width of edges [mm] 0.10 x 0.10; r = 0.21; ca. 60°		

TABLE 4. TESTING RESULTS WITHOUT AXIAL FEED, MATERIAL AL-ALLOY.

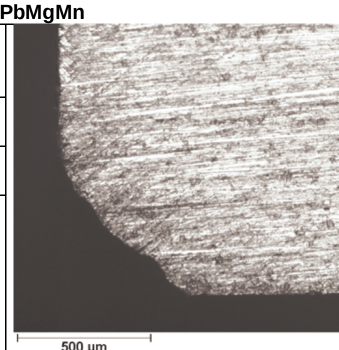
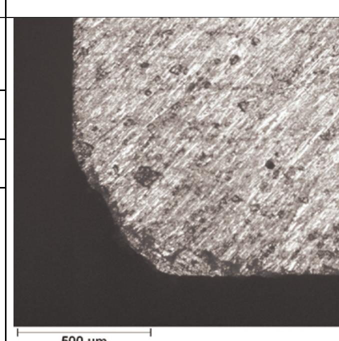
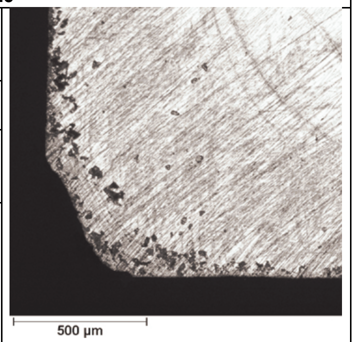
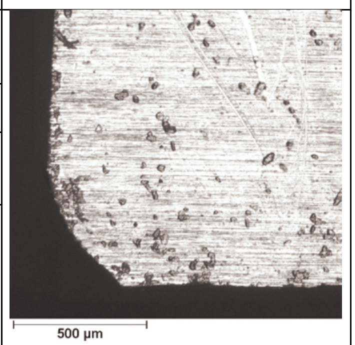
Material AW-AlCu4PbMgMn		
Rotational speed [1/min]	2000	
Pressure [bar]	4	
time of chip removal [s]	5.1	
Projected width of edges [mm] 0.49 x 0.48; ca. 45°		
Rotational speed [1/min]	2000	
Pressure [bar]	4	
time of chip removal [s]	5.2	
Projected width of edges [mm] 0.35 x 0.45; ca. 53°		

TABLE 5. TESTING RESULTS WITHOUT AXIAL FEED, MATERIAL X5CrNi18-10.

Material X5CrNi18-10		
rotational speed [1/min]	1000	
pressure [bar]	10	
time of chip removal [s]	Stop. after 60	
Projected width of edges [mm] 0.28 x 0.43; ca. 56°		
rotational speed [1/min]	1000	
pressure [bar]	10	
time of chip removal [s]	Stop. after 60	
Projected width of edges [mm] 0.29 x 0.37; ca. 59°		

COMPARISON OF THE CONVENTIONAL FLEXIBLE DEBURRING TOOLS WITH THE DEBURRING TOOL OPERATED BY DIRECT CONTROL.

Table 6 compares the properties of the flexible deburring tools from Cogsdill, Heule, and Dr. Beier-Entgrattechnik, when deburring cross-holes.

It can be observed that the deburring tools operated by direct control have a considerably higher range of application compared to the tools with spring bearing. During the tests, the maximum rotational speed was limited by the machine tool capabilities. Limiting values of rotational speed, feed and pressure of medium are not yet discernable.

SUMMARY

So far, only deburring tools with a spring bearing are known for internal deburring. Usable rotational speeds and feedrates are limited due to the spring. The consequences of this limitation are long deburring times and higher costs.

The development of deburring tools without spring elements, with direct control of the cutting edges by means of a medium (oil, air), allows for high-speed deburring (HSD) of internal and external features. Rotational speed and feedrate

can be increased considerably without affecting surface quality. Variation of pressure, feed and rotational speed allows control of the deburring quality, and it is possible to prevent surface quality deterioration.

TABLE 6. PROPERTIES OF FLEXIBLE DEBURRING TOOLS (DIAMETER OF MAIN BORE 9.8 MM).

Manufacturer	**Cogsdill**				**Heule**	
Deburring tool	Burraway		Burr-Off		Cofa	
Functional principle	Enters **only** the transversal bore hole; in order to remove the burr caused by **transversal boring** in the main bore					
Sense of rotation	**Only one** sense of rotation possible, **formation of secondary burr**					
Ratio D_{main}:$D_{transv.}$	>=3:1		>=2:1			
Size of transversal bore [mm]	2–3		3-5		4-5	
n° of cutting edges	1-2		1-2		1-2	
Cutting parameters	f_{max} [mm]	n_{max} [mm^{-1}]	f_{max} [mm]	n_{max} [mm^{-1}]	f_{max} [mm]	n_{max} [mm^{-1}]
Aluminum	0.2	600	0.2	900	0.4	600
Steel R_m<600	0.2	600	0.2	600	0.4	600
600<R_m<900	0.14	600	0.14	600	0.4	600
R_m>900	0.1	300	0.1	300	0.4	600
Stainless steel	0.1	200	0.1	200	0.4	600

Manufacturer	**Beier-Entgrattechnik**			
Deburring tool	Rubber tool		Directly controlled (pressurized air/drilling oil)	
Functional principle	Enters the **main bore**; in order to remove in the main bore the burrs caused by **all transversal borings**			
Sense of rotation	**left-hand** and **right-hand rotation**, **avoids formation of secondary burr**			
D_{main}:$D_{transv.}$	>=1:1 ($_{min}D_{main}$ ≈ 3.3 mm)			
Size of transv. bore [mm]	2–9.8		1–9.8	
n° of cutting edges	2-4		1-4	
Cutting values	f_{max}[mm]	n_{max}[mm^{-1}]	f_{max}[mm]	n_{max}[mm^{-1}]
Aluminum	0.2	400	0.6	2000
Steel R_m<600	0.2	400	0.6	2000
600<R_m<900	0.2	400	0.6	2000
R_m>900	0.2	400	0.6	2000
Stainless steel	0.2	400	0.6	2000

REFERENCES

Beier, H.-M., (2003), "Entgratwerkzeug zum Innen- u./oder Außenentgraten." (Deburring tools for internal and/or external deburring.) PCT – Patent. W003/084702 dated 16.10.03.

Jäntsch, St., Stollin M., (2003) "Untersuchungen zu direkt angesteuerten Entgratwerkzeugen." (Examinations on deburring tools operated by direct control.) FHTW Berlin, Thesis submitted for diploma.