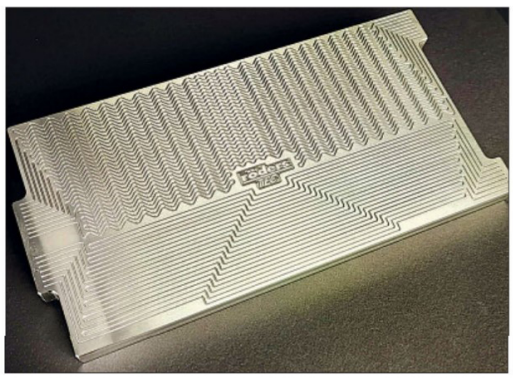
High-performance micro-milling of high-hardness steels: e.g. for bipolar plates

Tools for punching, embossing and forming sheet materials are very demanding. Accuracies in the range of 1-2 µm are sometimes required during production. The challenges increase the larger the tool and the thinner the sheet metal is. A prime example of these difficulties can be experienced in the production of stamping plates for the sheet metal shells for so-called bipolar plates for hydrogen fuel cells.

Speakers, left to right: Marc Maier (Open Mind), Dr. Oliver Gossel (Röders), Matthis Toppmöller (Hufschmied), Marc Geile (Voestalpine/Böhler), Matthias Schneider (Zeiss), Herbert Merz (MHT),Marco Giarrusso (Open Mind)
(photo: Klaus Vollrath)



Filigree channel structures on a demonstrator (300 x 150 mm) for an embossing die for bipolar plates for automotive fuel cells
(photo: Klaus Vollrath)

These thin hollow structures are made from welded sheet metal half-shells enclosing filigree flow channels. Together with the membrane electrode units sandwiched between them, numerous layers are arranged in regular order in so-called "stacks".

Sample workpiece (50 x 40 mm) with various surface structures typical of bipolar plates
(photo: Klaus Vollrath)

Politicians want to replace fossil fuels by promoting and favoring renewable forms of electrical energy. But since some tasks cannot be mastered using electricity alone, the development of a hydrogen economy is also being promoted. The fuel cell is thus seen as an alternative to the battery. This involves the use of so-called bipolar plates, which in the automotive sector consist of stamped, embossed and welded sheet metal half-shells forming hollow bodies. The bottleneck of this technology is currently the production of the required forming and punching tools. Thinner sheet metal would help to reduce the mass of the fuel cells. However, the thinner the material, the narrower the cutting gap the more precise the geometry of the tool must be. The accuracies to be achieved by the embossing and punching tools and the presses pose extreme challenges.

This requires the development of specifically adapted process chains for the manufacturing of embossing and punching tools for producing suitable sheet metal parts. Key aspects are the steel for the tools, the CAD/CAM software, the micro-milling tools, the properties of the machining center, the lubrication and cooling of the milling cutters and the metrological control and documentation of quality control. The companies *Hufschmied, MHT, Röders, Open Mind, Voestalpine* and *Zeiss* have joined forces on this project. The results currently achieved were presented at Hufschmied during a seminar with more than 50 participants. They are not only interesting for the core topic of "bipolar plates", but also offer promising insights for other sectors such as micro-production, precision mechanics, medical technology and aerospace.

Ultra-hard steel: Böhler K888 Matrix

In order to economically achieve the extremely fine structures of such bipolar plates, the embossing tool must have very high dimensional accuracy, good wear resistance and a low tendency to stick. Another prerequisite is good machinability. This requires a low proportion of primary carbides in a hard microstructure matrix ("matrix steel"). The carbides should be tiny and homogeneously distributed over the entire volume, as coarse specimens could break during machining and thus cause surface defects. This implies resorting to steels produced using powder metallurgy. Böhler K888 Matrix,

a material with a maximum carbide content of < 2 %, was selected. It is supplied in the soft-annealed condition with a Brinell hardness of < 280 HB and achieves a Rockwell hardness of 63 +1 HRC after hardening at temperatures between 1070-1120 °C. It is characterized by high wear resistance even in comparison with materials with a much higher carbide content. Machining tests at Hufschmied have shown that the material is nevertheless easy to machine and that very good surface qualities can be achieved. The material is also easy to coat, which also results in prolonged service life.

CAD-CAM software

A perfect NC program is essential for optimum workpiece quality. With its hyperMILL CAD/CAM system, OPEN MIND offers all the prerequisites for creating these NC programs. The software calculates the toolpaths with the utmost accuracy and thus delivers correspondingly precise NC data. A few points should be given particular attention to. In order to fully take into account the topology of the component when calculating the toolpaths, geometric features such as sharp edges, gaps and the nature of the surface transitions have to be analyzed and recognized. These inputs are considered in the calculations and control the point distribution in the tool path, for example. Further optimizations such as adjusting the feed rate are possible. This allows the milling tool to machine the component at a constant feed rate. A "smooth overlap" function avoids visible transitions resulting from the use of different milling tools or strategies and reduces the expenditure required for manual reworking to almost zero.

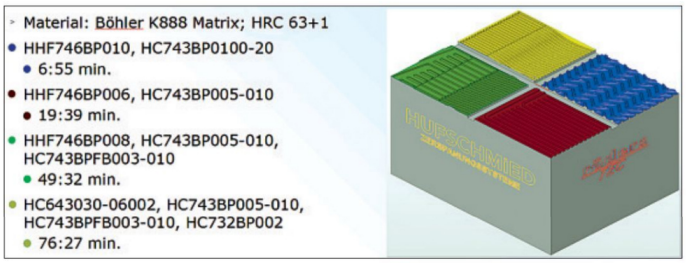
Another important feature makes it possible to link geometrically identical structures within a component, which are recognized or defined either automatically or manually. The corresponding toolpaths, which were first created for a single area, can then be brought to the previously recognized or manually defined positions via a transformation and linked fully automatically. Superfluous movements are eliminated in the process. This considerably reduces the computation times in the CAM system.

Requirements for the milling machine

The machining of embossing dies for bipolar plates is characterized by high material hardness, small milling cutters with diameters well below one millimeter, high demands on surface quality and accuracies down to the 1 µm range. The multiple small contour details also result in long machining times, thus requiring very good long-term thermal stability of the machine tool.

The demonstrator was milled in Hufschmied's technical center on this five-axis Röders RXP 501 DS; the system is equipped with the MHT medium distributor
(photo: Klaus Vollrath)

Röders' machine tools are particularly suitable for such precision machining tasks. Among other things they are characterized by frictionless direct drives, highly rigid roller guides, frictionless weight compensation of the Z-axis, precision HSC spindles and highly accurate tool measurement. An outstanding feature is the extremely high control cycle rate of 32 kHz in all control loops, which enables rapid correction of even the smallest deviations. Another decisive factor is the sophisticated temperature management by means of a temperature control medium that is kept stable at ± 0.1 K and circulates through all key components of the machine. This makes it possible to reliably maintain tolerances in the lower micrometer range.



The tools of the Bumble-Bi series made by Hufschmied used to process the various segments of the demonstrator (50 x 40 mm) on the Röders system, as well as the corresponding processing times
(graphic: Röders/ Hufschmied)

Bumble-Bi micro-tools from Hufschmied

The machining of embossing tools for bipolar plates is a particular challenge for the milling tools. This is due to the hardness of the material to be machined and the long running time of the programs, sometimes well over 100 hours. And the required accuracy only allows for low wear. Hufschmied developed the special "Bumble-Bi" series of micro-tools for this purpose. These include high-feed milling cutters for roughing as well as torus milling cutters, ball nose end mills and flat ball end mills. The latter are a kind of hybrid between torus and ball end mills. All tools receive a specially developed PVD coating, whose extremely smooth layers ensure good temperature management. The milling tools used to manufacture the sample and their application parameters are summarized in the table.

Hochvorschub Schruppwerkzeuge:

	HHF746BP	1 x D						63 - 66 HRC					
SR	Artikel	D1	D2	L2	L1	L3	ER	Z	VC	N	fz	Vf	ap	ae
	HHF746BP006	0,6	6	0,6	50	0,6	0,075	4	56,5	30.000	0,028	3.360	0,024	0,420
	HHF746BP008	0,8	6	0,8	50	0,8	0,09	4	65,2	26.000	0,037	3.880	0,032	0,560
	HHF746BP010	1	6	1	50	1	0,11	4	70,5	22.500	0,047	4.200	0,040	0,700

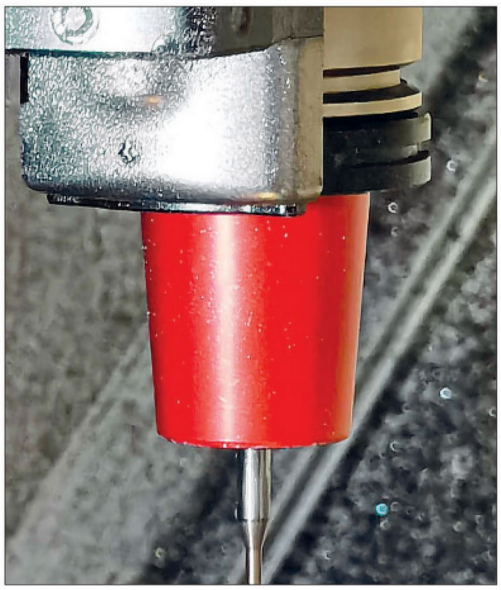
Torus + Flatballwerkzeuge:

	HC743BP	1 x D						63 - 66 HRC					
SR	Artikel	D1	D2	L2	L1	L3	ER	Z	VC	N	fz	Vf	ap	ae
	HC743BPFB003-010	0,3	6	0,3	50	0,3	0,1	3	35,8	38.000	0,021	2.390	0,009	0,075
	HC743BP005-010	0,5	6	0,5	50	0,5	0,1	3	50,2	32.000	0,028	2.660	0,015	0,200
	HC743BP	1 x D						63 - 66 HRC					
SL	Artikel	D1	D2	L2	L1	L3	ER	Z	VC	N	fz	Vf	ap	ae
	HC743BPFB003-010	0,3	6	0,3	50	0,3	0,1	3	45,2	42.000	0,016	1.980	0,020	0,050
	HC743BP005-010	0,5	6	0,5	50	0,5	0,1	3	62,8	40.000	0,021	2.510	0,020	0,100
	HC743BP010-020	1	6	1	50	1	0,2	3	94,2	30.000	0,032	2.850	0,028	0,200

Kugelwerkzeug:

	HC733+732	1 x D						63 - 66 HRC					
SL	Artikel	D1	D2	L2	L1	L3	ER	Z	VC	N	fz	Vf	ap	ae
	HC732BP002	0,2	6	0,2	50	0,2	0,1	2	31,4	42.000	0,013	1.060	0,010	0,014

Application data of the Hufschmied tools used to machine the demonstrator
(graphic: Hufschmied)



The hollow sleeve of the MHT media distributor encloses the tool holder without touching it or rotating with it; air and lubricant are supplied via the docking interface underneath the spindle
(photo: Klaus Vollrath)

Optimum lubrication with the MHT media distributor

The right combination of cooling, lubrication and removal of chips from the work area plays a decisive role in machining processes. The MHT media distributor enables a particularly efficient and at the same time cost and energy saving approach. The core element is a conical sleeve that is permanently assigned to the tool holder and is exchanged with it when the tool is changed, but does not rotate with the milling cutter. It is docked underneath the spindle and supplied with compressed air and lubricant from there.

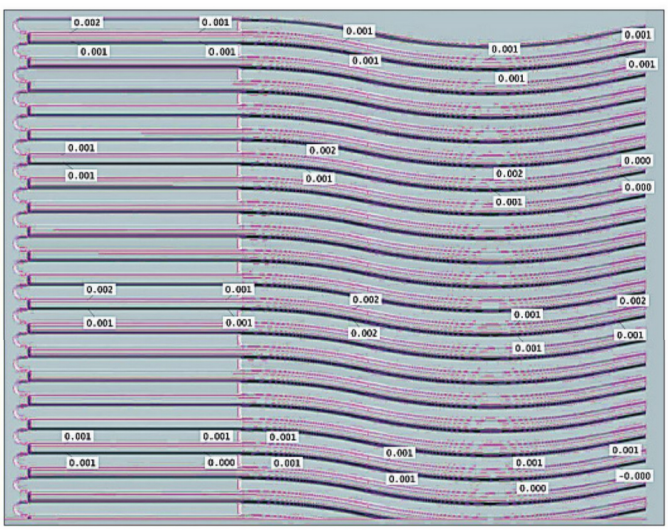
The main cooling and cleaning work is performed by compressed air ejected from nozzles arranged in a ring at the lower edge of the sleeve. This powerful air jet immediately removes the chips and their heat content from the milling cutter and the workpiece. The lubricating medium, consisting of carefully selected hydrocarbons, is supplied in extremely small quantities (2-10 ml/hour). This is nevertheless sufficient to optimally lubricate the cutting edges. During hard machining, the heat generated at the cutting edges is reduced by approx. 50 %. The main advantages are significantly longer tool lives, higher cutting performance of the machine and better workpiece surfaces.

Monitoring the demonstrator using the Zeiss DotScan optical sensor with an MPE of 1.8 µm + L/350; in order to be able to better measure the flanks, it was moved over the sample using a Zeiss "Contura" coordinate measuring machine with an RDS rotary swivelling unit
(photo: Zeiss)

Measurement technology and quality control

The milling cutters used in this project have diameters down to 0.2 mm. For quality control very small and narrow contour areas, e.g. on the flanks of the flow channels and on the cutting edges of the forming/stamping tools, must be monitored. As this involves recognizing details down to a single µm, the measurement uncertainty of the measuring system used should normally be ten times better than the production tolerances to be checked. However only a few coordinate measuring machines are up to such requirements.

In order to be able to record these measuring points with reasonable effort, a Zeiss DotScan optical sensor with a measuring rate of up to 1,000 measuring points/s was used, which was guided over the sample in three different angular positions using a rotary swivel unit.



The achieved quality of the component
(graphic: Röders)

Results

The results presented here (scatter ± 3 µm) demonstrate the efficiency of the process chain described. With the right choice of components and a suitable procedure, a high level of process reliability can be achieved even when machining high-strength or hard tool steels. In addition high quality requirements can be met. It should be emphasized though that this requires the consideration of all aspects of a given process chain in detail.

further information:
www.hufschmied.net // www.mht-gmbh.de // www.roeders.de //www.openmind-tech.com // www.bohler.de // www.zeiss.de