FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

FUNCTIONAL SURFACES AND MICRO MANUFACTURING

PROFILE

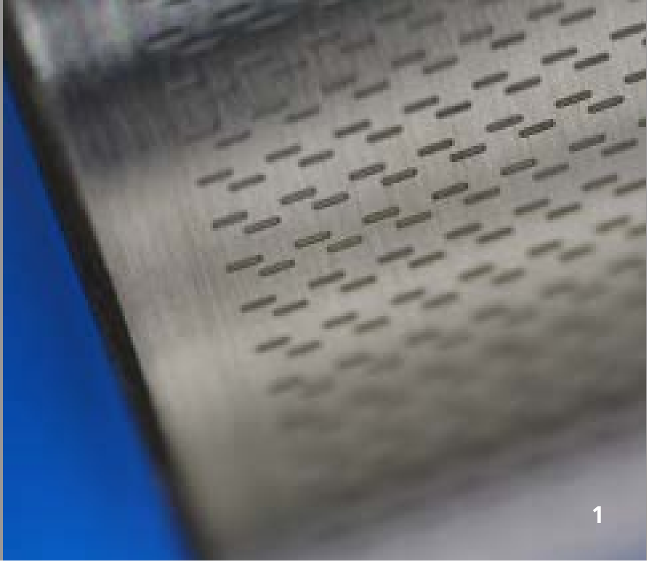
Components manufactured by precision engineering and microcomponents are mainly used in automotive engineering, mechanical engineering and tool making as well as in medical engineering and sensor technology. However, the textile industry, optics and the aerospace industry have also been demanding more and more functional surfaces and micro-structural components to meet their specific requirements.

The surface topography and near-surface boundary layer of a component have a decisive influence on its functionality, as the interactions with the environment and the technical system take place in this area. These include, for example, tribologically stressed surfaces, sealing and joining surfaces as well as functional surfaces for optical, thermodynamic, haptic or biological applications. Manufacturing processes and post-processes are used and modified specifically to set geometric and physical properties of the near-surface boundary layer to generate a functional surface on the workpiece. This results in a complex field of action that ranges from the energetic evaluation of manufacturing processes, extension of process limits, development of process combinations or substitution of operations, design of resource-saving process chains up to the point of developing special tools and machine technology.

The miniaturization of components and functional elements opens up new potentials in various areas of life. In medical engineering, for example, lost body functions can be restored by miniaturized implants, and in chemistry, microreactors make chemical reactions more reliable and profitable with smaller quantities of reagents. The smaller dimensions of the components also open up considerable potential for lightweight construction. Not only can material and energy be saved, but other effects and functional principles can also be utilized compared to conventional technology.

When miniaturizing components and functional elements, the ratio between component surface and component volume also changes considerably. This enables more intensive and dynamic interaction of the microcomponents with their environment.

The design and manufacturing of functional surfaces and miniaturized systems does not only require a high level of process understanding but also constant adaptation to current requirements. The Department for Functional Surfaces and Micro Manufacturing researches the associated challenges and develops tailor-made solutions for industry. This includes, for example, the development of electrochemical machining (ECM), spark erosion (EDM) and laser beam machining (LBM) in combination with machining or molding processes. We use measurement technology applying geometry and tribometry to evaluate and verify the effectiveness of the generated functional surfaces and microsystems. Current trends in our application-oriented research include the integration of actuator systems, which can stabilize processes, increase ablation and enhance precision. Further current research topics comprise the design of resource-efficient process chains for materials with macro and micro geometries that are difficult to machine, and the development of hybrid processes and process combinations for functional surfaces and microsystems.



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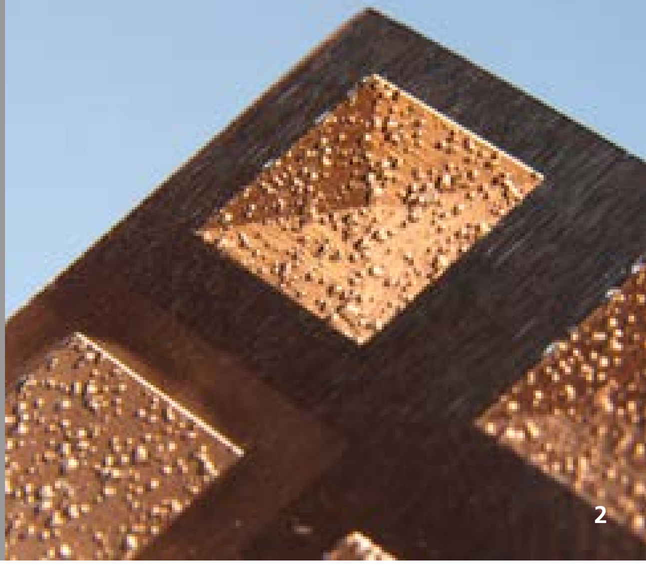

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FUNCTIONAL SURFACES

Surfaces and microstructures – Engineered surfaces

Structural and functional components are used in various fields of application. Surfaces designed to meet specific requirements are becoming increasingly important for optimizing these components depending on the application. Adjustable stress states and surface topographies – also in connection with coatings – can positively influence various component properties, e.g. with regard to flow resistance or tribological behavior. In addition to reducing friction losses, wear can also be reduced. Thus, functional surfaces contribute to environmentally friendly and energy-efficient solutions.

The manufacturing of functional surfaces can be directly integrated into the precision finishing of powertrain components. Using the example of boring and form boring of cylinder running surfaces in finishing quality, we shorten existing process chains, increase component quality and contribute to resource-efficient production. The development of minimum quantity lubrication and dry machining also increases energy efficiency in production.

In addition, we develop manufacturing processes and procedures that make it possible to permanently reduce friction and wear. This is achieved by production-integrated anticipation of the running-in process and the targeted formation of nanoscale boundary layers during finishing. This specially designed finishing process produces specific surface properties that have previously only been achieved after the fired running-in process of engine components.

Dimensioning

Specifically designed microstructures achieve a significant improvement in the friction coefficient of up to 40 percent over a certain load and speed range compared to unstructured friction partners, and show a uniform contact pattern on both contact partners. Among other things, the effects of structuring depend on the geometric parameters of the microstructures. This concerns both the lateral and vertical shape as well as their aspect ratio and the contact ratio of the microstructured surface.

Development of technologies, tools and process chains

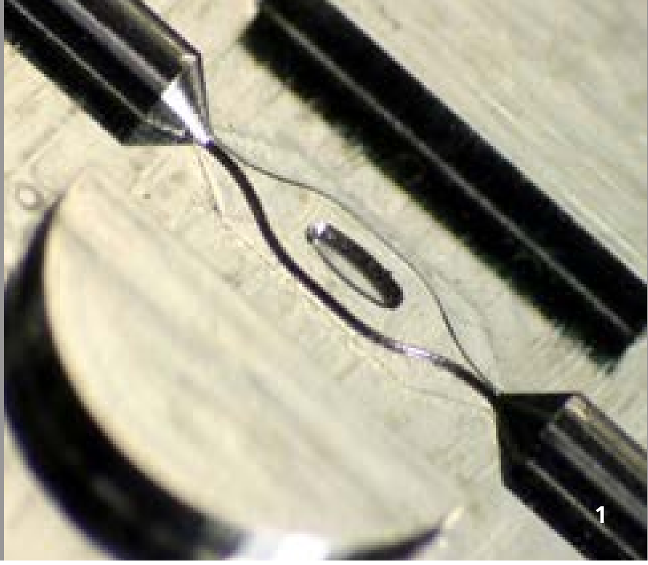
The reproducible and efficient production of large functional surfaces with a defined surface profile and surface layer requires basic and application-specific developments of technology, tool and process. Our investigations concentrate on the extension of the process limits by hybrid ablation and cutting finishing such as laser structuring, structure rolling, form boring and precise electrochemical machining.

Evaluation of surfaces and components

The evaluation and verification of the mode of action of the generated functional surfaces is carried out using geometric and tribometric measuring technology. For example, friction partners with newly developed surfaces are tested on rotary or translational tribometers, or on component test benches with continuous or reversing sliding movements close to operation, considering coefficient of friction and wear behavior.

1 *Buldging-free laser microstructuring of tribological surfaces*

2 *Micro machining of textures for injection molding tools*



MICRO MANUFACTURING

Microsystems technology and miniaturization
Both the miniaturization of components and the integration density of functional elements in complex precision systems are pioneers for innovative products. Individualized implants for medical technology, actuators and sensors for chemical and biochemical analysis technology, but also optics and special nozzles for space technology are example applications.

Miniaturized systems and integrative functional components are required in very different quantities – from mass products in automotive engineering to small series in mechanical engineering. A prerequisite for the production of these individual functional assemblies include both the know-how in highly developed precision engineering and processes of micro technology, and the used technology for tools and machines.

Our focus lies on the continuing development of electrochemical machining (ECM), electrical discharge machining (EDM) and laser beam machining (LBM) in combination with micro machining and micro forming of the surface. In the specific design of microtechnology processes and process chains, we concentrate on applications in the fields of microfluidic systems and microstructure components as well as micro tool engineering and micro mold construction. Manufacturing restrictions are already analysed in the design phase and taken into account in component dimensioning and material selection. On this basis, we can design reproducible and reliable process chains.

In the field of manufacturing processes of micro technology, we do not only develop solutions for generating complete geometries and 5-sided machining or for expanding the machinable material spectrum to include metals and ceramics that are difficult to machine. We also develop hybrid technologies using superposition of axes, vibration or media. Research topics deal with process analysis, simulation and optimization, but also with application-specific technology developments and prototype production. A deeper process understanding is required for machining biocompatible materials or shape-memory alloys and titanium alloys with precise shapes in the sub-millimeter range and specific surfaces. The research challenges lie in economic efficiency, component quality, tool wear, process reliability and reproducibility.

In addition to extending the process limits for precision and micro machining, it is also necessary to qualify the corresponding machine and measuring concepts. Together with established plant manufacturers, for example, we have developed an innovative drive concept for a hybrid structural machine. A considerable reduction in energy consumption is achieved by this concept, in addition to an almost mechanically decoupled axis movement with accuracy well into the sub-micrometer range. From an economic and ecological point of view, the compact design of the micro cutting machine at table height with few individual components is a cost-effective and energy-saving alternative to larger and more complex machining centers for the construction of small molds and tools.

With our know-how, state-of-the-art machining centers and a CAD/CAM system specially designed for micro machining, we are your competent partner for services, feasibility studies and preliminary research.

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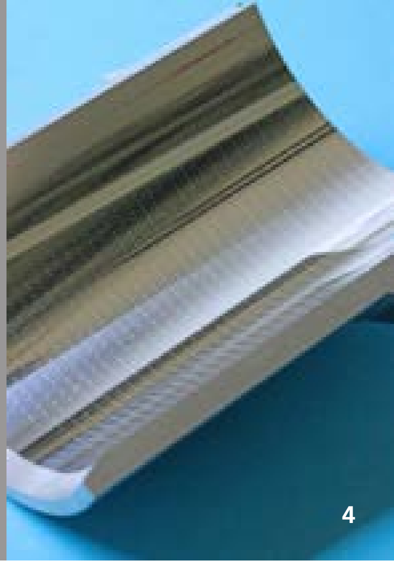

4

TECHNOLOGIES AT A GLANCE

Electrochemical Machining (ECM)
Electrochemical machining involves the removal of workpiece material by anodic metal dissolution. The most important feature of EC processes is the lack of mechanical contact between tool and workpiece. This means that no mechanical forces are transferred and material properties such as hardness or toughness have no influence on the process. ECM technologies are therefore ideally suited for machining highly stressed components, and enable the production of high-quality, always burr-free surfaces with high shape accuracy.

We mainly qualify electrochemical ablation with closed electrolytic free jet (Jet-ECM) and precise electrochemical metal machining (PECM). Depending on the material to be processed, the achievable accuracies for the processes range from 10 to 100 micrometers. Roughnesses of up to Ra = 0.05 micrometers can be achieved. Our research focuses on the localization of the ablation area, on process simulation and optimization, application-specific development of technologies and devices, and on efficient prototype production.

Laser Structuring
Laser material processing enables selective structuring of functional surfaces and micro components. We work with a 5-axis system in which a fiber laser and an ultrashort pulse laser are arranged in parallel. Using high pulse energies and ultra-short pulse times, the material is removed with virtually no thermal influence on the boundary areas. The process is used for components with matt/gloss effects, antimicrobial, hydrophobic, tribological or interference surfaces.

Our research focuses on 2½D microstructuring of embossing tools for hot embossing medical fluid systems and on surface structuring of technical components to reduce friction and improve demolding behavior. Subjects of current investigations also include the transfer of the findings to 3D structures and the combination of laser material processing with micro milling.

Electrical Discharge Machining (EDM)
Micro spark erosion is based on electrical discharges between workpiece and tool electrode, which melt or vaporize small volumes of material. Several tens of thousands of discharges per second transfer the tool geometry into the workpiece. The process allows the use of soft, easily machinable electrode materials. To produce the smallest geometries with the highest precision, the process-related spark gap must be minimized, which makes particle removal in deep structures more difficult. In order to be able to produce high-precision microgeometries quickly and reliably, we are researching hybrid technologies in which the EDM process is superimposed with low-frequency vibrations and ultrasonic vibrations. Such strategies enable a significant increase in process stability and removal rate, which implies an extension of the possible microstructure spectrum up to high aspect ratios and complex geometries. The transfer of micro EDM processing to electrically non-conductive ceramics is also subject of research.

1 *Microfluidic tool with structure sizes of 50 µm*
2 *Ultra-precision machining of optical surfaces*
3 *Precise electrochemical metal machining*
4 *Microstructured piston system running surface*

Micro Milling

Micro milling is carried out with filigree tools in the diameter range of a hair. With speeds of up to 150,000 revolutions per minute, cavities and miniaturized components are manufactured to be used in tool and mold making, in micro analytics, in the automotive sector and in medical engineering. Materials with a hardness of up to 65 HRC can be machined by 3- to 5-axis simultaneous milling. This requires a high level of process reliability to ensure effective workflows. Investigations of cutting force, tool displacement and process temperature contributed to a deeper understanding of the process and the limitation of tool wear. Now systematic developments for adapted milling strategies, optimization of cutting values as well as concepts for cooling lubricants also enable high-precision manufacturing processes in micro machining.

Cutting Finishing

A machining center with integrated mechatronic mounting of a milling spindle was developed for finishing by metal cutting. This system enables preventive machining of non-circular bores in components that distort during subsequent assembly or during their operating behavior, such as cylinder liners, bearings or guideways. The mechatronic mounting of the milling spindle allows high-frequency tool deflections of up to approximately 100 micrometers. Current research topics deal with managing the different cutting engagement conditions caused by deflection, the development of shape-related control strategies as well as the identification of optimal process parameters for form boring processes in cycle times of the automotive industry.

1 *Highly dynamic form boring of cylinder surfaces*

2 *Double-sided micro lens array, hot embossed in glass with 1700 single lenses (diameter 25 mm)*

In addition, developments are performed for the design of tools and cutting edges as well as developments for the extended use of tool deflection for the economic production of surface modifications on flat components.

Replication / Hot Embossing

Isothermal hot embossing is used, among other things, for the production of surface-functionalized plastic films, for hermetically sealed joining of glass and metal components, but also for reproducing structural elements of micro optics and microfluidics. Double-sided hot embossing of array structures in optical quality is a unique field of activity worldwide. To this end, we implement developments for process modeling to describe the flow behavior of inorganic glass as well as technologically appropriate designs for tools and equipment.

Structure Rolling

Structure rolling is a combination of processes that we have developed from roller burnishing and structure embossing. The structured embossing roll used in this process can be used, for example, to reduce the initial roughness while simultaneously embossing microstructures for tribological effects. But the process can also be used effectively for roughening surfaces for subsequent coating. We are currently investigating the applicability of the process to non-rotationally symmetrical components.

Tribometry

Friction and wear have a negative effect on product life and for this reason also on the use of resources. This makes tribological evaluation of component surfaces all the more important. With translational and rotary tribometers we can simulate application-related operating conditions. For sliding combinations of technical and medical products, but also of lifestyle products, we determine the running-in behavior and the influence of cryogenic and temperature-controlled lubricants or modified or new finishing processes and coatings.

OUR RANGE OF SERVICES

Innovations are an essential factor for entrepreneurial success and are best achieved when business and science go hand in hand. We are a reliable and competent research partner for both medium-sized and large companies when it comes to generating innovations from ideas and developing solutions to problems.

Our services include
– Design of components and surfaces,
– Technology development for micro and precision manufacturing using cutting, ablating and forming,
– Tool development and
– Quality assurance, sampling as well as geometric and functional component evaluation.

We cooperate in various forms with partners from industry and research:
– Contract research for companies with and without public co-funding
– Joint developments with companies and universities in publicly funded collaborative projects, especially in the field of fundamental and preliminary research
– Services for component production as well as for evaluation of quality and functionality
– Providing companies with the latest machinery and plant technology for testing and research purposes

For interdisciplinary tasks, we work closely with other research institutions and specialized companies. Thus, we are in a position to offer complex system solutions.

Equipment / Plant technology

Cutting
– 3-axis high-performance machining center Mikron VCP1000
– 5-axis micro machining center Kugler MM3
– 3-axis micro machining center LPKF XY 10/10 GLP
– Jig grinding machine MIKROMAT 4S
– Various minimum quantity lubrication systems

Ablation processes
– PEM Center 8000 for electrochemical machining (ECM)
– 3-axis micromachining system for Jet-ECM
– Micro EDM fine boring machine Sarix SX100 & T1-T4
– 5-axis laser machining center ACSYS ORCAµ

Replication / Forming
– Hot embossing machine MicroShape 100
– Precision Forming Machine P.U.MA 600 for Micro Hot Embossing
– Universal testing machine TIRAtest 2700
– Test stand for high-speed microforming

Cleaning
– Micro sandblasting system Texas Airsonic HPB
– Mobile CO_2 snow jet cleaning system ACP JetWorker P16

Geometry and surface metrology
– 3D CMM Zeiss Prismo
– Scanning electron microscope REM VP 1455 with EDX system
– White light interferometer, MikroCAD strip projection system
– VCheck contour measurement software
– Renishaw laser interferometer
– Compact Mass Spectrometer QMS 220

Tribometry
– Translatory tribometer Optimol SRV5
– Rotary tribometers WAZAU TRM 500 and TRM 5000

Editorial notes
Fraunhofer Institute for
Machine Tools and Forming Technology IWU
Reichenhainer Strasse 88
09126 Chemnitz, Germany

Phone +49 371 5397-0
Fax +49 371 5397-1404
info@iwu.fraunhofer.de
www.iwu.fraunhofer.de

Department Functional Surfaces and
Micro Manufacturing
Dr.-Ing. Jan Edelmann
Phone +49 371 5397-1931
Fax +49 371 5397-1930
jan.edelmann@iwu.fraunhofer.de

Front Cover
Components of a titanium implant with electrical feed-through and optical window for infrared data transmission for a myoelectric hand prosthesis control (Fraunhofer lighthouse project Theranostic Implants)