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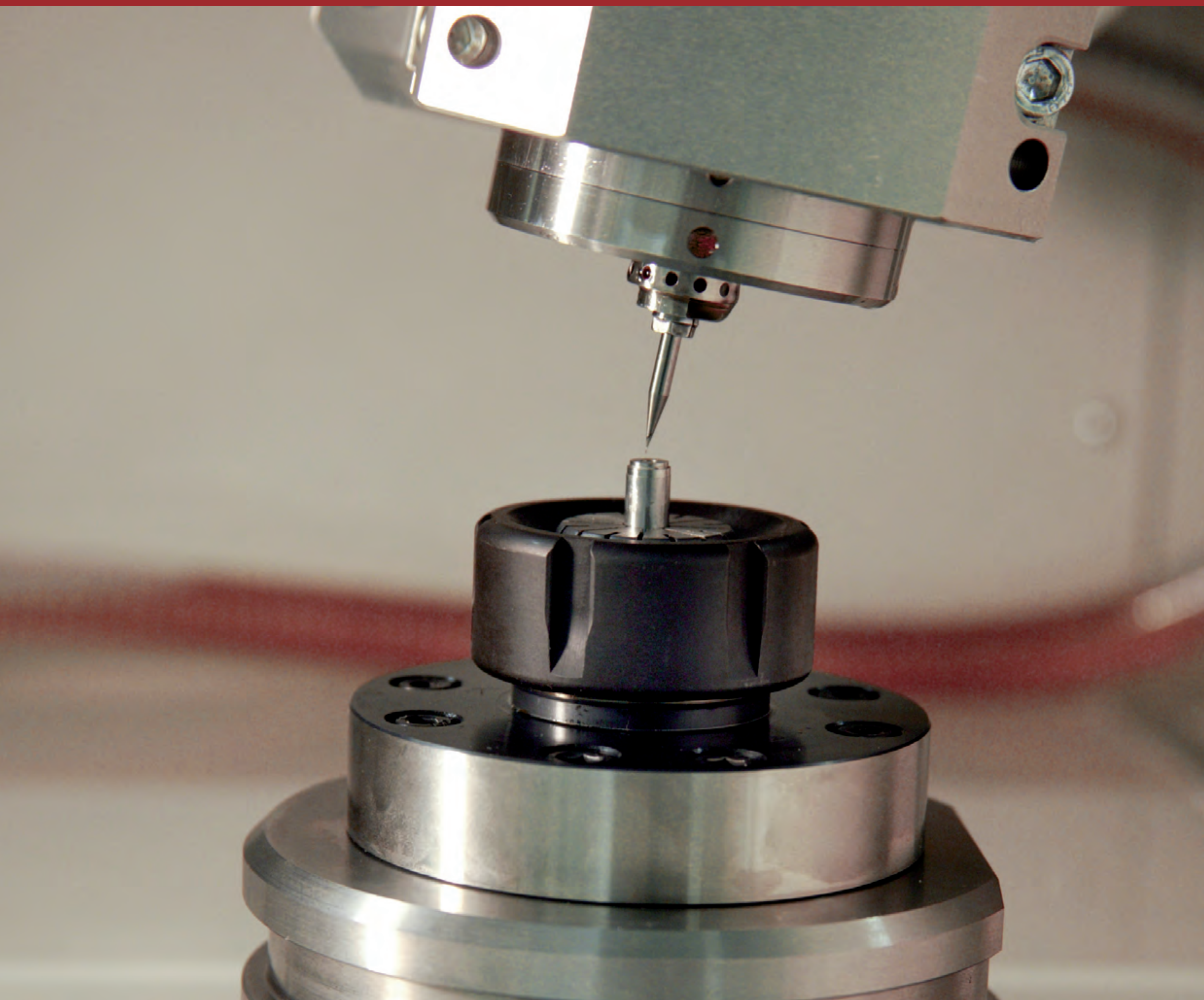
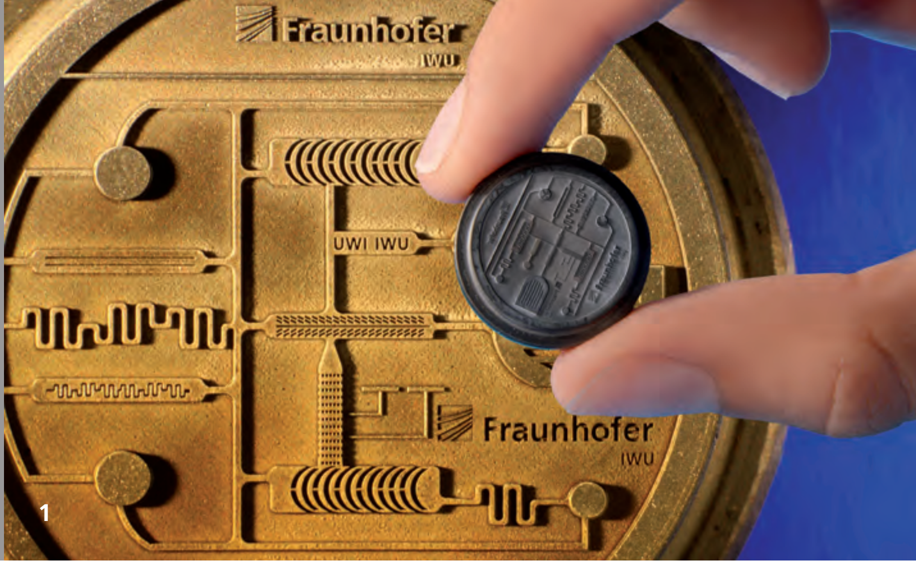
FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

PRECISION- AND MICROMANUFACTURING





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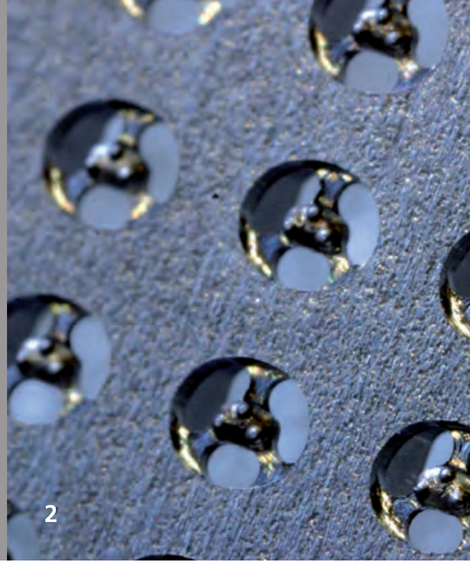
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POTENTIAL AND APPLICATIONS

Miniaturization

The miniaturization of parts and functional elements is opening up whole new areas of potential in diverse areas of daily life. In medical engineering, miniaturized implants are restoring lost body functions, in chemical applications, micro-reactors are ensuring that chemical reactions require smaller amounts of reagents and can take place in a safer and more controlled process, using smaller amounts of reagents. At the same time, miniaturization of the spray holes in fuel injection systems is permitting environmentally friendly combustion engines with low consumption levels to be designed and manufactured.

As part dimensions become smaller, engineers are tapping into the considerable potential of lightweight design and construction, permitting materials and energy to be saved in some cases and in others, using effects and functional principles not generally associated with classical engineering. The changing dimensions of components and functional elements from the millimeter to the micrometer range, is altering the ratio of part surface to part volume significantly. Consequently, there is substantial scope for more intensive and dynamic interaction between the micro-components and their environment.

Surfaces and micro-structures – Engineered surfaces

The importance of being able to create a specific surface structure for structural and functional components in a diverse range of areas of application is increasing steadily with the requirement for continuous optimization of these parts. A number of different part characteristics can be influenced via adjustable states of stress and micro-structured surfaces, sometimes in conjunction with coatings and tool modifications. Elevated or recessed micro-structures can be used to exert positive influence on the flow resistance or tribological behavior of parts used in automotive manufacturing. In addition to reducing frictional losses, it is possible to limit the extent and severity of wear sustained by the part. In this way, micro-structured surfaces make a valuable contribution to environmentally friendly and energy-efficient solutions.

Optical functional parts with absorbent, refractive and reflective characteristics complement the range of applications of micro-structured surfaces. Forming processes in conjunction with tool making capable of producing micro-structured tools from high-strength, wear-resistant materials, are ideal particularly where high quantities of large parts are concerned.

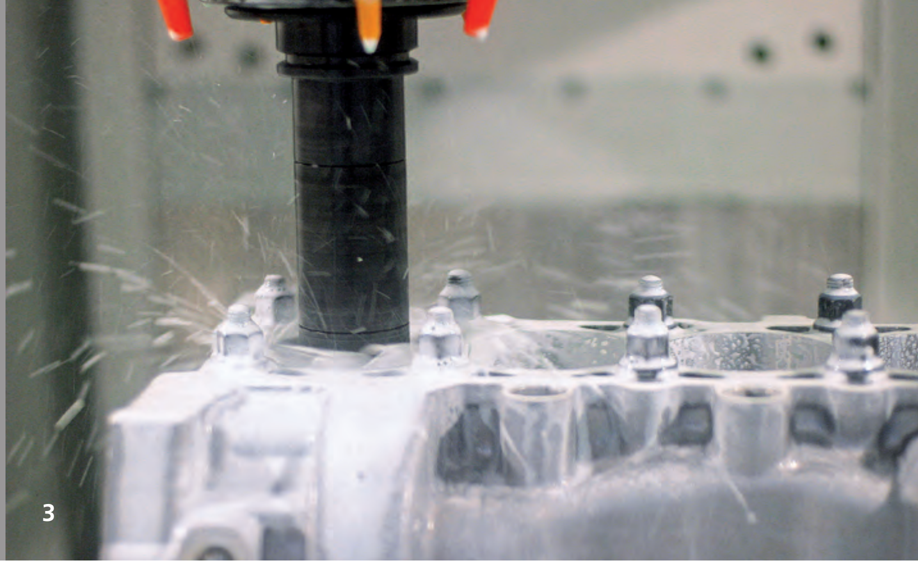
Precision

High levels of geometrical part precision coupled with clearly defined pre-machining quality of the surfaces to be structured are essential if the surfaces and microstructures are to match or exceed expectations. To this end, high-precision machining processes using geometrically defined cutting edges are being developed, which will ensure that energy-efficient, damage-free finishing operations can be conducted on a diverse range of materials.

Technologies

The requirement for replicable and reliable manufacture of micro-parts and micro-structured, functional surfaces, presents a particular challenge to industry. The following sub processes are therefore offered as services:

– Production-oriented design of parts and structures
– Selection and assessment of materials from a manufacturing point of view
– Development of tools for micro-engineering applications
– Technology development and process chain design
– Application and process-specific development of machine tools, equipment, handling technology, characteristics and process metrology



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CUTTING TECHNOLOGIES

The development of cutting techniques which use defined cutting edges in high-precision and micro-machining operations includes the analysis and optimization of process parameters in machining operations conducted on high-strength and highly heat-resistant materials. Depending on the process involved, there are a number of synergetic effects between macro and micro-machining, which can usefully be exploited.

Finish-machining high-precision components

Continuous optimization of the manufacturing processes is vital in the quest to enhance component quality and to ensure resource-efficient manufacture, thus giving the company a competitive edge. One approach pursued in the effort to achieve this, is to shorten existing process chains by widening the boundaries of the process. The finish-machining operation conducted on cylindrical bearing surfaces by drilling in manufacturing grade IT3, is an example of this. The percentage of the machining operation performed using a defined cutting edge – a cost and resource-efficient finishing technique, is thus further extended. The on-going sophistication and refinement of minimal lubrication and dry machining techniques, is further contributing to increased energy efficiency in manufacturing.

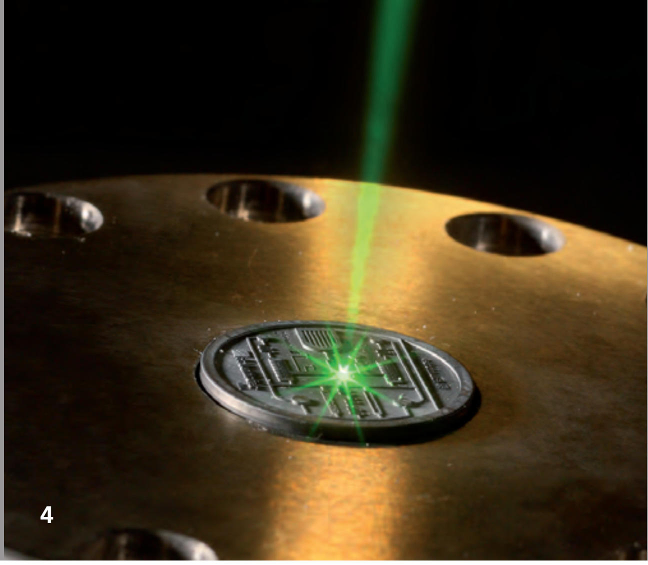
In addition to this, manufacturing techniques and processes are being developed, which achieve lasting reductions in friction and wear by anticipating the running in process and forming carefully selected boundary layers with thickness measurable in the nanoscale range in the course of precision machining operations conducted on engine components. The objective behind this work is to develop manufacturing technologies for the production of geometrically high-precision components with appropriate surface geometry and to produce ultra-fine crystalline boundary layers using a geometrically defined cutting edge. Thus, selected surface properties, which have previously been reached only after the fired running in process, are produced during the manufacturing process.

Micro-milling for prototypes as well as for tool and mold making

In addition to application in tool and mold making, micro-cutting operations are becoming increasingly important in the manufacture of parts needed for small batch production. The applications are primarily in the micro-analysis, automotive, medical engineering and clock making industries. Customers are increasingly demanding equipment capable of machining high-strength and hardened materials. Accordingly, technological development at the Fraunhofer IWU is concentrating on developing strategies to meet the requirements of micro-hard milling operations conducted on materials up to 65 HRC. The focus in these investigations is on feasibility, tool wear, process reliability and consistency.

Systematic developments in customized milling strategies, milling cutter displacement, cutting forces and cutting value optimization as well as lubrication concepts for micro-machining, are enabling filigree tools with diameters measuring only a hair-breadth to achieve enviable tool life durations even when confronted with significantly more demanding operational requirements. Areas of 62 HRC hardened, alloyed, cold work tool steel exceeding 4,000 mm² can be finish-machined reliably and consistently, for example, without tool change in micro-hard-milling operations. The surface roughness achieved in these operations is between Rz 0.6 and 1.6 µm.

1 *Silicon carbide embossing mold*
2 *Middle ear implants produced in a batch fixture*
3 *Process investigations into boring of cylinder holes*



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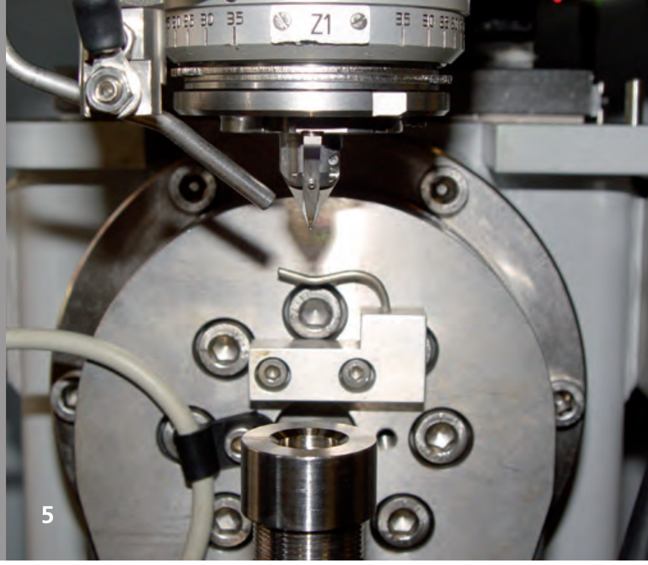

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MATERIAL REMOVAL

Material removal processes permit precision finish and micro machining operations to be conducted on a diverse range of materials, irrespective of their mechanical properties such as high levels of hardness or toughness. This largely force-free type of machining offers significant benefits in terms of ultra-high precision and smallest structures.

Electro-chemical precision machining

Technological developments in the field of electro-chemical manufacturing methods, focus on expanding the range of materials which can be machined (metals which are difficult to machine) and the development of hybrid technologies which permit material removal operations to be integrated within the manufacturing process chains. The areas of research relate to the investigation of the process itself, localization of the area dissolution, process simulation and optimization as well as to the application-specific development of technology and equipment and prototype manufacture. The subjects of the investigations are electro-chemical machining using a closed electrolytic jet (Jet-ECM) and high-precision electro-chemical metal machining (PECM). The EC process is used to produce basic geometries and secondary shaped form elements, to finish machine parts, to produce micro-structures in part surfaces and to produce tools.

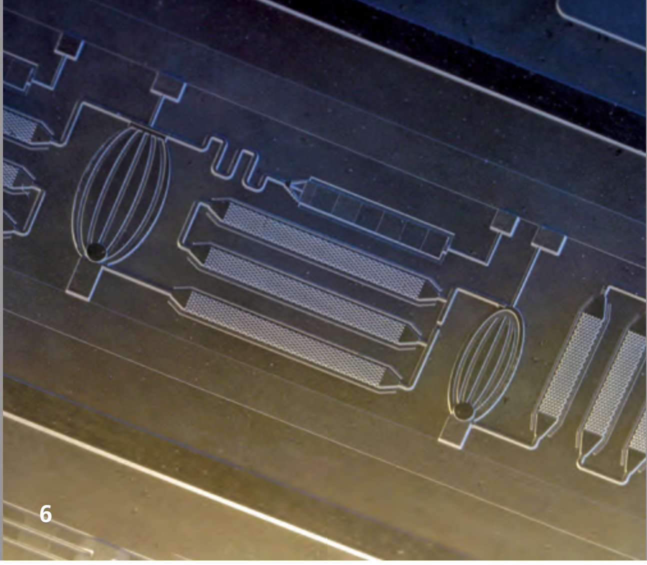
Micro-electrical-discharge machining

Micro-electrical-discharge machining is based on electrical discharges between the workpiece and the tool electrode, in the course of which, small volumes of material are fused or vaporised. Tens of thousands of discharges per second transfer the electrode geometry to the workpiece. This process permits soft electrode materials, which are easy to machine, to be used. When micro, high-precision geometries are produced, the discharge or spark gap required by the process must be minimized, which makes it more difficult to remove the particle debris from the machining area, particularly in the case of deep structures such as micro-bore holes.

At the Fraunhofer IWU, research is under way to optimize micro-EDM machining in order to permit high-precision micro-geometries to be produced swiftly and in consistently high quality. One focus of investigation, in addition to detailed process analysis involving electrical and geometrical indicators, is on hybrid technologies, in which low frequency and ultra-sonic vibrations are superimposed on the EDM process. Strategies of this nature permit a significant increase in process stability and in the speed at which debris is removed from the machining area, thus expanding the potential range of micro-structuring to include high aspect ratios and complex geometries. Research is also being conducted into the option of transferring expertise in high-precision micro-EDM machining to other materials which are difficult to machine, including electrically non-conductive ceramics.

Laser surface-structuring of micro-geometries

Laser-assisted micro-structuring permits a diverse range of structures and materials to be precision-machined in processes whereby material is removed via laser ablation. On-going work at the Fraunhofer IWU is concentrating on 2½D micro-structuring of embossing tools for hot-embossing medical fluid systems and on surface-structuring technical components in order to achieve a reduction in friction co-efficient among other things. Methods of transferring expertise acquired in this investigation to 3D structures and means of combining laser machining with micro-milling are likewise subjects of current research.



MICRO-FORMING

The fields of application for micro-forming technology, include structuring large surfaces and mass manufacture of serial components. Components, machine tools and processes are all part of the investigative process in order to ensure optimum outcomes.

Hot embossing optical and fluidic components

The objective in the field of forming processes conducted on glass and plastic materials, is to guarantee that structures can be transferred in replicable, cost-effective and reliable processes using hot embossing technology. Elements which contribute to the solution include the following:

– Process description/simulation
  by characterizing the process parameters, investigating the viscosity-temperature properties of relevant types of glass used in the hot embossing process and by process modelling in order to describe the flow characteristics

– Improving reproduction accuracy
  by correcting systemic form deviations, machine tool system development and developing the technology to emboss arrays on both sides

– Innovative coating strategies
  by exploiting the advantages of glass coating, by investigating the effect on adhesive forces and sticking occurrence and by optimizing coatings

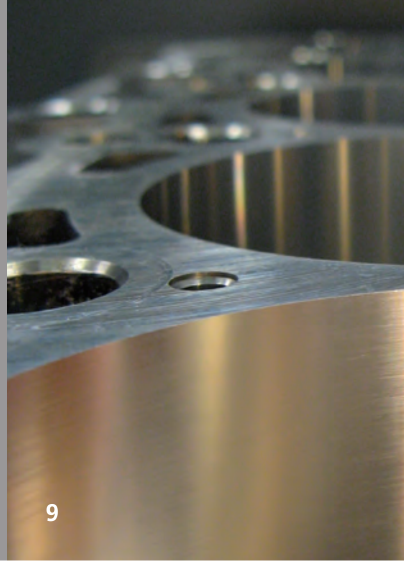
Hot embossing is used to manufacture surface-functionalized plastic film and to reproduce structural elements in micro-fluidic applications. Lateral dimensions in excess of 20 micrometers and aspect rations of up to 5 can be achieved.

An additional section is concerned with the economical and cost-effective manufacture of optical components in isothermal hot embossing operations. The focus in this area of investigation is on micro-structuring wafer-type components. Both the solutions to the problems surrounding double-sided hot embossing operations conducted on array structures and the innovative coating technology applied in glass pressing operations in order to increase effectiveness and minimize tool wear, are unique in the world.

The results are applied
– in the development of micro-forming tools for hot embossing and injection molding,
– in micro-fluidic sensors used to analyse blood or urine values,
– in micro reaction technology,
– in mobile diagnostics systems, and
– as optical components (for example individual lenses and arrays of lenses).

This field of activity is completed by technology-oriented design, tool system and industrial manufacturing equipment activities.

4 Micro-structuring via laser ablation
5 Hybrid micro FDM process with ultrasound overlapping
6 Micro-fluidic chip
7 Micro lens array stamped on both sides



METROLOGY AND TRIBOMETRY

One of the main elements in micro-production is metrological quantification of the micro-structures and geometries produced. High precision measurement of the components permits reconciliation with the programmed geometry; however, it is vital to evaluate surfaces and to identify wear characteristics. To achieve this, optical measuring methods capable of high-precision evaluation and characterization of a diverse range of surfaces, geometries and materials are absolutely essential.

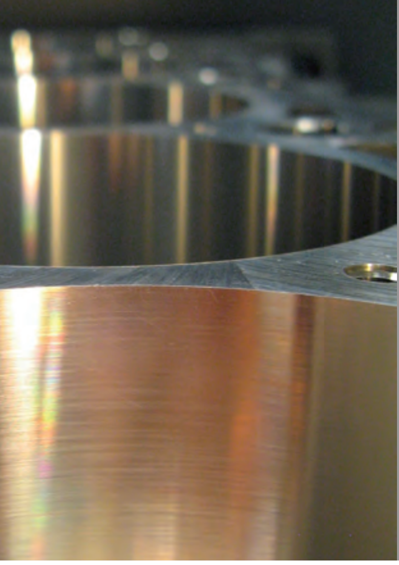
The wide range of available measuring methods ensures that virtually all requirements in terms of geometrical metrology can be met. Additionally, machining processes can be characterized by combining several measuring procedures.

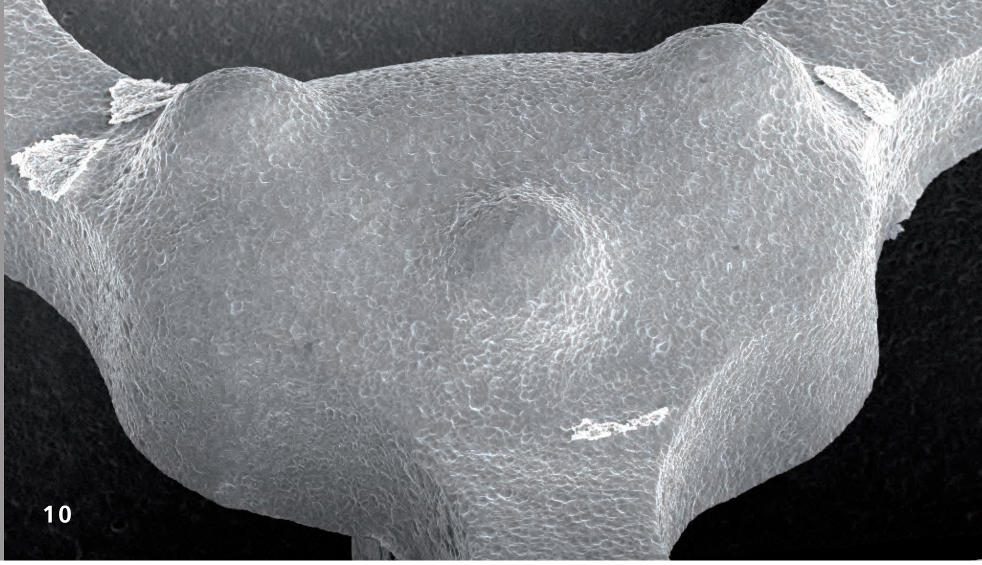
The Leo 1455 VP scanning electron microscope permits sample surfaces made of a wide range of materials and in different qualities to be presented clearly in high-contrast images with very good depth of focus and a three-dimensional effect, achieved by exploiting a range of contrast mechanisms which can be interpreted with ease. An x-ray micro-area-analysis can also be performed using the SEM. The optical measuring techniques of fringe projection, confocal microscopy and white light interferometry permit high-precision measurement of the size, shape and roughness values of structures.

Complex workpiece geometries are evaluated using the Zeiss Prismo S-ACC high-precision coordinate measuring machine with a measuring probe and integrated rotary table. The researcher engineers and technologists thus obtain qualitative information to feed into ongoing investigations. Use of a wide range of software packages extends the scope of measuring options from standard geometry through gear tooth measurement to freeform area measurement, thus rendering them suitable for complete testing. In addition to measuring geometries themselves, the geometries can be compared to the CAD data and sophisticated components can be digitized efficiently to agreed deadlines.

Tribological properties are measured using the two rotational tribometers manufactured by the company WAZAU which are available at the Fraunhofer IWU. These tribometers are used to investigate friction and wear. The TRM 500 and TRM 5000 tribometers differ in terms of normal force and friction torque. Electron microscopic examination, which permits the wear tracks to be shown in high-precision images and also permits material compositions to be analysed, is used to investigate and evaluate wear processes. Application-specific trials relating to the tribology are also conducted.

8 *Microstructured test specimen for minimizing friction*
9 *Engineered surfaces of cylinder liner*
10 *Middle-ear prosthesis (final process)*





OUR RANGE OF SERVICES

The range of services offered, includes the following:

– Component design
– Development of the technology required in cutting and forming micro and high precision manufacturing processes
– Development of the tools required, as well as
– Quality management, sampling and part evaluation.

Medical technology is one of the areas of application for miniaturized and micro-structured components. The development of manufacturing technologies for miniaturized implants used to restore the functionality of the ossicular chain in the middle ear, is one such example. This was achieved by micro-milling titanium parts with main dimensions of a few hundred micrometers in order to manufacture complex, three-dimensional geometries. The realization of suitable clamping concepts and the application of material removal and beam techniques in order to manufacture biocompatible surface structures, complete the process chain.

The manufacture of larger parts is essential for applications in the automotive industry. A large number of ultra-high precision, high load capacity and energy-efficient components are used in the power-train. Geometries with extremely high levels of form accuracy with defined surface properties and tribologically oriented properties can be manufactured using high-precision finish machining techniques such as drill finishing. A number of tests are conducted in order to assess the properties, including tribometer tests performed under conditions typical of those to which cars and automotive parts are exposed.

Industrial manufacturing equipment

Cutting

– Kugler MM3 5-axis micromachining center
– Mikron VCP1000 3-axis high-performance machining center
– LPKF XY 10/10 GLP 3-axis micro-machining center
– MIKROMAT 45 jig grinding machine
– A range of minimal lubricant systems

Material removal

– High-precision 3-axis-micro-EC machining facility
– PEM Center 8000 (precise-electro-chemical machining)
– JenLas epidot 4 laser micro-structuring machine
– Posalux FP-1 micro-electrical discharge precision drilling machine

Forming

– MicroShape 100 hot-embossing machine
– P.U.M.A 600 high-precision forming machine for micro-hot embossing applications
– TIRAtest 2700 thermal micro-forming universal test machine
– High speed microforming testing equipment
– 5-axis precision positioning machine for micro-assembly

Cleaning

– HPB Texas Airsonic micro-sand blasting
– ACP Jetworker P16 mobile CO2 sand blasting cleaning system

Tribometry, measuring and evaluation technology

– WAZAU TRM 500 and TRM 5000 rotational tribometers

Geometry and surface measuring technology

– Zeiss Prismo 3D coordinate measuring instrument
– Ocular high-precision 5D measuring microscope, confocal microscope
– White light interferometer, MikroCAD fringe projection system
– Vcheck contour measuring system
– REM VP 1455 SEM with EDX system
– Renishaw laser interferometer
– QMS 220 compact mass spectrometer

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