MACHINE SYSTEMS FOR THE PRODUCTION OF COMPLEX OPTICAL SURFACES
Progressive lenses for eyeglasses are one example of optical freeform surfaces. By contouring the glass with a non-rotation-symmetrical surface, a gradient between individual dioptrers for near-field and far-field vision can be included in a single lens. Simple freeform surfaces can also be found in metal mirrors for laser-assisted machining. Varying local curvatures on the mirror surface are used to shape the intensity of the laser beam. Intensity profiles can thus be varied almost at will and may require quite complex mirrors for high-end applications.

Freeform surfaces can also be used for polymer lenses that are replicated through injection molding. Shrinkage in the polymer that occurs after molding can be compensated by adjusting the form insert with a freeform shape. This opens up new possibilities for injection-molded parts, which can now enter high-precision markets typically dominated by more expensive glass lenses. Each kind of freeform surface has its own requirements regarding surface accuracy, surface roughness and production efficiency and costs. The Fraunhofer IPT continuously develops new and improved machine systems for the manufacture of optical freeform surfaces.

Applications for freeform optics

- Injection molding inserts with lowest surface roughness for polymer optics
- Prototyping of optical elements and systems, e.g. as test series for new lens designs
- Complex laser mirrors for laser-assisted machining, design and manufacture

Our processes

- Ultra-precision turning and ruling/shaping
- Slow- and fast-tool turning
- Milling, fly-cutting
- Local (corrective) polishing

Our machines

- Precitech Nanoform 350 ultra-precision turning lathe with piezo-driven fast tool for microstructures and air-bearing fast tool for freeform generation
- Moore Nanotechnology 350 freeform generator with fast tool and Y-axis for freeform surfaces and linear microstructures
- LT Ultra MTC410 ultra-precision turning lathe with fast tool and B-axis for single-point turning
- LT Ultra MMC1100 ultra-precision turning machine for fly-cutting and milling of freeform surfaces
- dSpace RCP (Rapid Control Prototyping) for fast and effective testing of proprietary control loops individually attuned to specific processes
- Tactile sensors for rotationally symmetrical spheres and aspheres
- Interferometer and coordinate measurement machines for measuring freeform surfaces
For manufacturing non-rotation-symmetrical surfaces, fast-tool- and slow-tool-supported turning machines are used. By machining with diamond tools, workpieces with optical surface quality and almost any geometry can be manufactured. This process is used for manufacturing optical freeform surfaces in metal that guide and shape the impacting light beam in any desired way, e.g. for laser machining of materials. Complex freeform surfaces are also used as mold inserts for injection molding of polymer optics. Such lenses enable optimized light-beam guidance for focused lighting of selected areas. This helps to make lighting systems, such as streetlights, more efficient.

**Benefits of fast-tool/slow-tool machining**

- Due to the continuous cut, the surface roughness is much lower compared to freeform milling (surface roughnesses of < 5 nm on freeform surface in nickel-phosphorus)
- Machining time is much shorter than with line-by-line milling and grinding of optical elements
- Using adapted clamping devices, several workpieces can be machined on the face in a single setup

**Our services**

- Manufacturing of prototypes and verification of producibility in small batch series
- Investigation of producibility of complex freeform surfaces
- Process development for diamond machining, design of machining strategies for cost-efficient manufacturing of workpieces
- Concept and design of fast-tool/slow-tool systems for customer-specific requirements

**Our skills**

- Many years of experience in the design and implementation of fast-tool systems; the first such system in Europe was developed by the Fraunhofer IPT
- Internal development of control algorithms to ensure highest form accuracy of freeform surfaces
- Existing systems for microstructuring (piezo fast tool), surface manufacturing (aerostatic fast tool) and steel machining using hydrostatic slow-tool axes
Conventional CNC manufacturing reaches its limits when it comes to machining optical workpieces. The typical programming scheme, G-Code, dates back to the 1960s. The last major innovation was the development of contour control and the interpolation of multiple axes in the 1970s-80s. Further developments concentrated on modern CAM software and enhanced control hardware, which can now process programs on the scale of several hundred megabytes. However, the fundamental problem, the discretization of the surfaces into point clouds and tool trajectories, still limits the manufacturing of highly precise optical workpieces. To solve this issue, the Fraunhofer IPT has refined contour control to a surface-based control. For the first time ever, machines can access the real surface information and do not need to interpolate points, with the resulting unavoidable interpolation errors. Error is minimized through the use of adapted control structures. Thus, the new approach enhances both the form accuracy and the surface roughness of optical freeform geometries.

Benefits of the system-specific control and software solution

- A flexible control platform enables control parameters and algorithms to be adjusted to the given problem, because microstructures place different demands on the system than freeform mirrors
- A surface-based processing of geometry setpoints, not yet implemented in conventional machines, frees manufacturing from interpolation errors
- Adapted control systems consisting of special components can be clocked at a significantly higher rate, enhancing the surface quality of the manufactured workpieces

Our services

- Development of complex control systems for applications that need fast and highly precise control concepts
- Integration of client-specific surface description formats into the machine control if the native machine interpolation is not sufficiently precise
- Modeling and control optimization of the machine as a whole or of individual axes to improve positioning dynamics and accuracy

Our skills

- Surface geometry information is processed during manufacturing in the control system itself, which is more precise than conventional CNC control systems can be according to the applied data conversion algorithms
- The comprehensive adoption of surface-based measuring methods enables the correction of optical freeform geometries, especially for injection molding cavities
- From design to correction, a consistent data format is used, eliminating potential interpolation errors
Due to their high degree of hardness, extreme durability and thermal behavior, steel molds with optical freeform surfaces are in great demand for the replication by injection molding in large batch production of optical components. The manufacturing of optical freeform surfaces in steel is limited based on the fact that the mirror finish and form accuracy cannot be achieved by means of diamond machining processes. For this reason, pre-machined freeform surfaces need to be finished by manual or automatic grinding, lapping and polishing operations in order to achieve a mirror-finish surface with high surface integrity.

Benefits of automatic zonal polishing

- Due to the automatic approach, relevant process parameters can be reliably adjusted and controlled
- A special process kinematic ensures a mirror-finish surface free of textures and scratches
- The correction of form deviations and purposeful modifications of the mold in order to avoid shrinkage during the replication process are possible with computer-controlled polishing (CCP) in combination with a dwell-time algorithm
- Polishing tool development allows the machining of a great variety of geometries

Our services

- Feasibility studies, design and development of polishing systems according to the requirements of our customers
- Development of machine systems and adaptive polishing heads with special tool kinematics for zonal polishing operations
- Zonal, dwell-time and force controlled polishing of prototypes and small batches

Our skills

- Control system development for dwell-time-controlled polishing for active form corrections and form design of the mold
- Development of customer-specific finishing tools for almost any polishing task
- Many years of comprehensive experience and pooled knowledge in the design of polishing strategies
- Finishing solutions for conventional die and mold making
- Holistic consideration of the manufacturing process using a consistent data format, from optic design to corrective polishing and subsequent replication process
Fraunhofer Institute for Production Technology IPT
Steinbachstraße 17
52074 Aachen
Germany
Phone +49 241 8904-0
Fax +49 241 8904-198
info@ipt.fraunhofer.de
www.ipt.fraunhofer.de

Contact

Dr.-Ing. Christian Wenzel
Phone +49 241 8904-220
Fax +49 241 8904-6220
christian.wenzel@ipt.fraunhofer.de

Dipl.-Ing. Roland Tücks
Phone +49 241 8904-152
Fax +49 241 8904-6152
roland.tuecks@ipt.fraunhofer.de