Machining of complex free form plastic optics with several optical surfaces referenced to each other

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Abstract

Today's optical industry shows a clear trend towards more precise optical surfaces, leaving regular geometries and moving towards the wildest forms and shapes optical designers are capable of imagining. Within the process chains for generating such surfaces some of the greatest challenges are:

- Absolute referencing of surfaces in respect to each other – free forms have to be referenced in all 6 degrees of freedom within nm-accuracy
- Data-handling – CAD / CAM software has to be tuned to safely handle nm-resolution for modeling free forms and calculating accurate NC codes
- Tool / machining strategies – complex structures tend to lead to machining strategies with long process times

The focus of this paper is a complex plastic optic with several high-end free forms as well as other optical surfaces referenced to each other and the challenges in their process chains.

1. Free form process chain from optic design to tool path generation

The typical process chain for such optics is always very similar and starts with the beam calculation by the optic design and the generation of point clouds for each optical surface. All calculated point clouds are given to the optics design software in an A-master reference system. In the second step the point clouds have to be transformed into 3D CAD models. For this, the point clouds must be converted to surface descriptions; they have to be extended, traced, tailored etc. and aligned in the work piece coordinate system B. Step 3 is to define the optimum machining strategy with respect to the surface needs, choose the tools and perform tool path generation in the machine coordinate system C. These 3 steps sound easy but often several issues occur. The first issue is the different reference systems. Euler transformations are needed; standard software is often already limited in the proper rotation of single complex surfaces in nm-resolution and best fit calculations of free form surface positions are not sufficient. One approach for referencing with higher accuracy is to design optics with all required optical surfaces and reference marks in one piece. In this way the fine-tuning of several optical elements with respect to each other is not necessary. To achieve this, an optic design was calculated for all surfaces including their positions in respect to each other. The required footprints of the optical elements were connected with each other into one piece with minimum distances. Reference marks especially for absolute alignment of free form surfaces are shown in Figure 1. All these reference marks can be machined together with the surfaces in one setup and with an intelligent selection all positions, tilts, orientations etc. are definable.

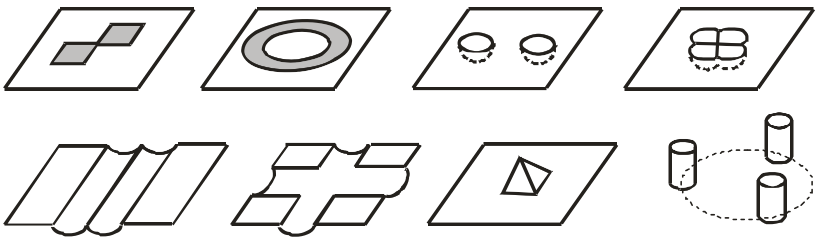

Figure 1: Types of ref. marks, points, rings, spheres, crosses, pyramids, cylinders.

Besides the necessary coordinate transformations and referencing of surface extension, the tracing and tailoring of free-form surfaces in the CAD model and proper tool path generation with CAM software are the next challenges. Such data handling issues have already been discussed in several euspen publications. With typical mathematical surface descriptions and conventional CAD / CAM software, free-form surfaces are almost always influenced in their optical aperture; in addition tool paths are often limited in minimum gaps, in the statistical arrangement of tool path points and 5-axis anti-collision tests e.g. to achieve the ultra-precision range with given CAD / CAM facilities. In this project the software packages were adjusted in cooperation with a CAM supplier. The goal was to achieve the accuracy of 1nm and to enhance calculation speed by the use of 64 bit and multi-core technology. After years of collaborative effort, a stable software solution for ultra-high accuracy is now available. Examples of tool paths achieved for multi surfaces in one cut, reference points, smooth tool lead in /outs e.g. are given in Figure 2.

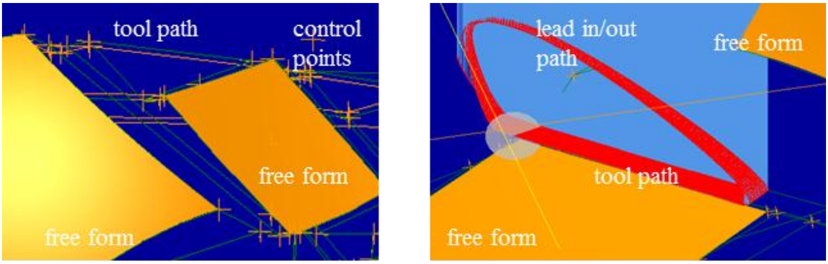

Figure 2: Several tool path setups for free form milling and planing including smooth lead in/out strategies.

2. Free-form figuring and finishing

With the complexity of this optic, STS turning is not an option. Ball-end milling and planing would be the usual choice of processes for these kinds of complex parts. But in order to reduce machining time and achieve an optimum micro topography, the parts were machined only by planing. In this way machining time could be reduced by approximately 35% and further optimization is still in process.

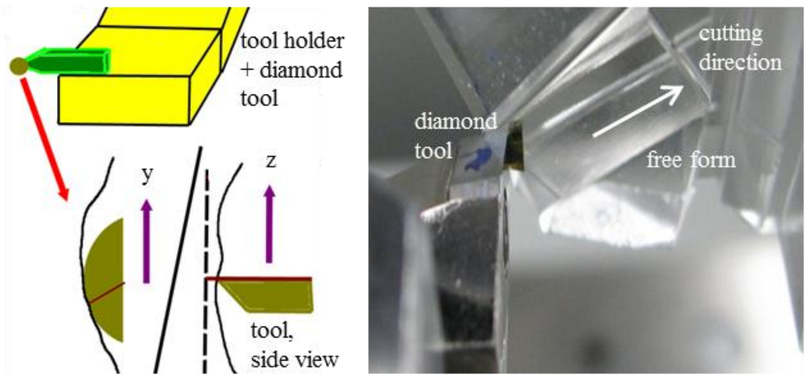

Figure 3: Typical mcd radius tool setup for free form planning; close-up of the setup.

Several diamond machining tests were completed to define the optimum deterministic and economic strategy. The micro-topography value achieved is shown in Figure 4, left. Measurements with WLI indicate a roughness of 5.2 nm rms and this result, as well as the form accuracy of < 5 µm PV, seemed to be the limit for the given surface / optical element designs for this plastic material.

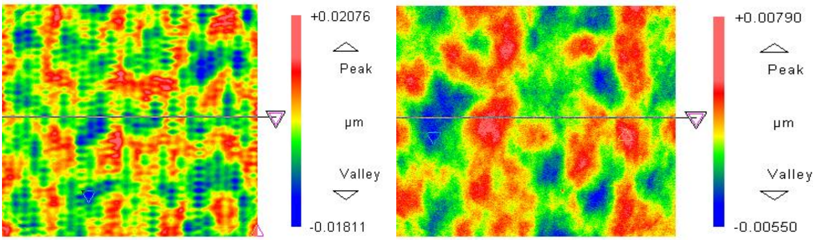

Figure 4: Left: 5.2 nm rms achieved on a plastic optic using diamond machining;
Right: 1.4 nm rms achieved after short-time iterative semi-auto. finishing

The above rms value which was achieved as well as the surface frequencies were not sufficient for this plastic optic. In order to reduce stray light the roughness had to be three times lower than the above-mentioned rms value. Therefore and because the free form design could not be changed, an additional finishing process has been developed. This iterative semi-automated polishing process developed by Zeiss enables the rms value to be reduced to approx. 1.4 nm in minutes, as shown in Figure 4, right.

3. Conclusion

An ultra-precision process chain for producing high quality multi free-form plastic optics has been achieved at Zeiss. A combination of absolute referencing, high-end CAD / CAM software, diamond machining and finishing guarantee first prototypes in (sub-) micro meter form and nano-meter roughness accuracies.

Acknowledgement / Reference

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