Asphere and Freeform Measurement 101

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This work culminates the previous “Aspheric Lens Contour Deterministic Micro Grinding 101” and “Aspheric Lens Sub-Aperture Polishing 101” articles by Shai Shafrir, and Scott Bambrick. The precision optics industry is gradually moving toward increasingly complex optical designs. Aspheres are becoming a large portion of manufactured optics. Metrology for these optical shapes is a challenge and various measurement methods have individual strengths and weaknesses. OptiPro has developed a novel solution named UltraSurf, a non-contact measuring system using state of the art, precision motion control. Optipro designed the UltraSurf to further the manufacturing capabilities of companies producing complex precision optics.
Metrology Challenges

Common optical measurement methods for aspheres and freeforms have limitations with surface roughness, slope error, and deviation from best-fit sphere. A profilometer drags the tip of a stylus across the surface of the optic. The height of the probe tip is displayed on the screen creating a two-dimensional profile. A desired asphere is then fit to this profile, leaving behind the residual error. A coordinate measuring machine (CMM) is able to measure freeforms and aspheres by contacting the part at discrete points with a stylus. Null corrector optics are commonly used to gather interferometric data on asphere optics by correcting the wavefront reflected from the part. Computer Generated Holograms (CGH) are also used for interferometric measurements, and work in a similar fashion as null corrector optics. In the measurement setup, a CGH and null corrector optics are placed between the interferometer’s transmission sphere and the optic being measured. A stitching interferometer combines several sub-aperture interferograms to produce a full aperture image of the asphere.

Contact profilometers are surface slope limited. The profilometer tip is susceptible to slip errors during on-axis measurements, and lateral force errors for off-axis measurements of high-departure aspheres and freeform surfaces. Similarly to a profilometer, a CMM has to contact the optic for measurement, and calibration of the stylus tip is crucial. Null corrector optics and CGH can allow interferometric measurements on aspheres and freeforms, but can be difficult to align, limited by departure, and cost prohibitive for small runs of parts. Stitching interferometry is susceptible to high-departure aspheres and freeforms. All interferometric methods require the part under test to be polished, limiting these measurements to the final stage of fabrication.
Description of UltraSurf
The UltraSurf measures with a non-contact probe. It uses five axes of motion to scan the probe over the surface of the part, keeping the probe perpendicular throughout the scan. The scanning method of the UltraSurf overcomes slope and departure limitations of interferometric and profilometer metrology. The machine layout is shown in Figure 1. Each axis of motion is an air bearing. The linear axes are driven by linear motors, and the rotary axes are brushless direct drive. High-resolution scales coupled with the air bearings allow for smooth motions with accurate positioning.

Figure 1: UltraSurf Axes of Motion, probe moves with Z and B axes, part moves with X, Y, C axes.

Measuring with UltraSurf
OptiPro has developed the UltraSurf to measure optical surfaces automatically. The operator must first enter the shape of the part into the UltraSurf software. Currently spheres, aspheres, and flats are supported with the easy to use graphical interface. Next, the operator will block the part on the machine using any preferred method. Commonly sticky tapes, wax, and even vacuum are used. For a rotationally symmetric part such as an asphere, the operator will then roughly center and remove tilt from the part using control knobs on the C-axis. The non-contact probe and guidance from the software are used to accomplish this task. Finally, the operator will locate the part on the machine by performing “touch-off” on the center of the optic with the non-contact probe. After this short alignment procedure, the
UltraSurf will automatically scan the probe over the optical surface. The result is a point cloud representation of the optic under test.

The UltraSurf currently uses two different non-contact probe technologies. One probe senses the distance from the probe to the part using white light and chromatic confocal sensing (CCS) (Figure 2). The other probe is able to sense the distance from the probe to the part and the thickness of multiple surfaces using low-coherence interferometry (LCI) (Figure 3). This probe is ideal for measuring window parts because it can measure both surfaces and thickness during a single measurement.
Point Clouds to Error Maps
The final measured point cloud can be compared to the desired shape using OptiPro’s UltraSurf software. The comparison is a multiple stage process. First, the point cloud goes through the registration stage, where the cloud is overlaid with the desired shape. Second, manufacturing parameters such as radius are changed slightly. An error map is calculated, and the process returns to the beginning until the point cloud is properly registered and manufacturing parameters have been optimized as shown in Figure 4 below. After the measurement, deviation from the ideal shape is calculated and available for further analysis in the UltraSurf software, or available for export into other data analysis packages. In addition, the data can be used as correction feedback into deterministic grinding or polishing machines, such as OptiPro’s eSX and UFF.

Figure 4: Point cloud fitting process
Results

UltraSurf is able to measure a wide variety of aspheres. OptiPro was tasked to measure an asphere that has 1900 waves of departure from the base sphere. The asphere also had approximately 20 waves of irregularity on top of the high departure, making it very difficult to measure with conventional metrology. UltraSurf measured asphere using the CCS probe, and the data can be used to deterministically correct the optic. The data is shown in Figure 5 below.

Figure 5: Asphere surface error map
Similar to a torus, an anamorphic asphere can have two different curvatures in its orthogonal axes. Asphere polynomial terms can be added in these two directions to add further complexity to the shape. UltraSurf measured the anamorphic asphere in Figure 6 using the LCI probe and a five-axis scanning path.

Figure 6: Anamorphic asphere, photograph of part (top) surface error map (bottom)