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Automated asphere centration testing with AspheroCheck UP

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ABSTRACT

With aspheres being incorporated in optical designs across all industry fields, there is high demand for fast and flexible metrology solutions for aspheric lenses. While many systems support measuring the surface topography, the process is limited to a specific design or based on a time-consuming scanning process. Centration measurement with such systems requires additional probes or the inclusion of external reference surfaces in the measurement process.

In this paper, we present AspheroCheck UP [1], a highly automated lens testing system based on the well-established AspheroCheck principle. The paraxial centering errors of both optical surfaces are measured in reflection using a focusing autocollimator. This centration measurement is combined with a fully motorized, non-contact distance sensor that measures the aspheric surface run-out. All three measurements can be performed in parallel during a single rotation of the sample, greatly reducing overall measurement time. The sensor can also be used for referencing to outer diameter, flange and/or interlock surfaces and even double-aspheric lenses. A five-axis motorized table enables the automatic alignment of the optical axis of the sample to the rotation axis. This significantly reduces setup time and allows for fully automatic testing without user interaction, ensuring both high measurement accuracy and high repeatability independent of the operator.

A full cycle time of less than 1 minute including loading and unloading is possible, enabling applications in both R&D and production environments. In addition to supporting ISO and Q-type polynomial surfaces, the system supports most other rotationally symmetric surface types, including Fresnel and diffractive surfaces.

Keywords: aspheres, metrology, centration, production, quality control

1. INTRODUCTION

Due to the growing demand for optical systems with both high imaging quality and reduced size and weight, more and more optical designs now include aspheric lenses. Imaging properties that required multiple spherical surfaces in traditional designs can be achieved with a single aspheric surface, and virtually all types of aberrations can be compensated using specific asphere designs. Recent advances in manufacturing technologies greatly reduced the per-unit costs for both low and high-volume productions, from diamond turning of single glass lenses to batch injection molding of plastic lenses for the mobile phone market. The majority these designs are rotationally-symmetric.

With the widespread adoption of aspheres comes the need for fast and reliable metrology for monitoring the production process and for quality control. Unlike traditional spherical lenses, aspheres may exhibit shape errors that cannot be compensated for by alignment and thus reduce the overall performance of the optical system. It is therefore crucial to measure the quality of single aspheres prior to using them in optical assemblies.

Aspheres may exhibit two types of shape errors: The aspheric surface itself may deviate from the nominal design, or the front and rear surfaces of the lens may be misaligned. Which of these error types is more common depends on the manufacturing process, with centering errors being the main cause of degraded performance on molded lenses.

While the aspheric surface shape can be measured with a variety of both contacting and non-contact processes, only a few processes allow measuring the centering error directly. Since both optical surfaces need to be included in the same coordinate system, existing processes often require measuring external reference marks and manually reversing the sample for a single measurement. The time and operator requirements for these processes make them unsuited for large-volume testing. In addition, contacting probes damage the optical surface or coating, leaving scratches or indents on the optical surface.

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We introduce a metrology system for automatic centering error testing of aspheres that uses a combination of autocollimator-based centration measurement and non-contact surface displacement measurement using an optical distance sensor.

2. MEASUREMENT PRINCIPLE

2.1 Centration error of optical surfaces

For measurement of the centration error of an optical surface, there are different methods established for production. The most common technique utilizes focusing autocollimator, and the focal point is moved into the center of curvature of the top lens surface, as shown in Figure 1. The reflected light from the lens surface is imaged onto a camera, while the sample is rotated. The movement of the reticle image on the camera describes a circle, and the radius directly correlates with the centration error of the measured surface with respect to the axis of rotation.

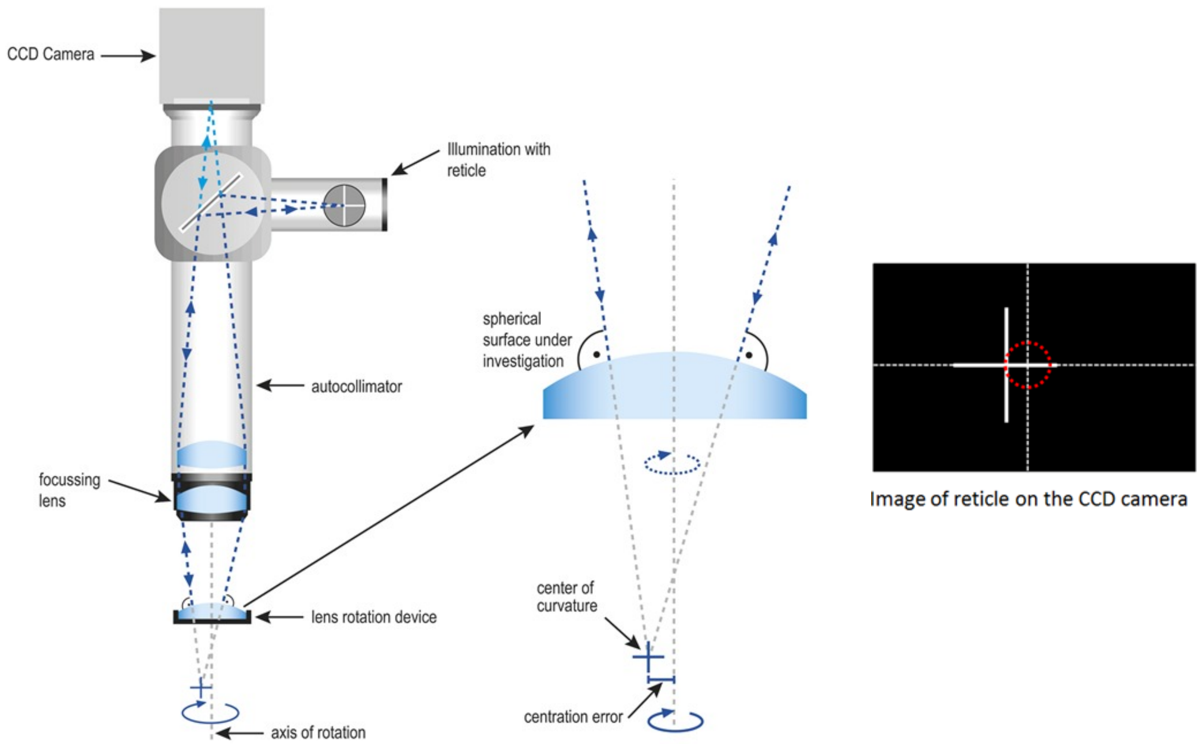

Figure 1: Measurement of the centration error in reflection mode with autocollimator and reticle

This measurement technique for a single surface is simple and cost-efficient and thus widely used in production. It can be applied for plane surfaces (using collimated light without focusing lens) and spherical surfaces with short and long radii. Most aspheric surfaces follow a near-spherical shape in the paraxial region, and diffractive surfaces emulate the refractive properties of spherical surfaces, so the same technique can also be applied to the paraxial regions of these surface types.

Using a second focusing autocollimator, the centering error of the second surface of a single lens can be measured using the same principle in just one rotation. The two centers of curvature can be connected to form the optical axis of the lens. In principle, spherical lenses can always be aligned based on the optical axis to achieve maximum performance.

If measurement from the bottom is not possible, both centers of curvature can also be measured using only one collimator. Since light passing through the first lens is refracted, the focus position for the second surface needs to be calculated in advance, and the centration of the first surface has to be included in the calculation of the second surface centration error. This principle, also referred to as MultiLens, is described more closely in [1] and [3].

2.2 Asphere measurement principle

Unlike spherical surfaces, rotationally symmetric aspheric surfaces do not have a single center of curvature, but an axis of symmetry. This axis is generally referred to as the asphere axis. The paraxial center of curvature is part of the asphere axis and of the optical axis of the lens, but the asphere axis may be tilted with respect to the optical axis. Such an inner centration error is an inherent property of an aspheric lens that cannot be removed by alignment, resulting in reduced optical performance. Therefore, inspection of single aspheric lenses prior to installation in optical assemblies is essential.

Since the autocollimator-based measurement only covers the paraxial region of the asphere, additional information is required to measure the aspheric surface location. Assuming the aspheric surface matches the nominal design of that surface, the asphere tilt can be measured by observing the displacement of the pre-aligned lens during rotation, as described in [4].

The sensitivity of the measurement varies with the position of the distance sensor on the aspheric surface. The highest displacement for a given axis tilt is observed when the distance between the paraxial center of curvature and the intersection between the surface normal and the asphere axis is maximized. For most aspheric designs, this is true for the edge of the lens that usually also exhibits the largest deviation from the spherical base shape, as shown in Figure 2.

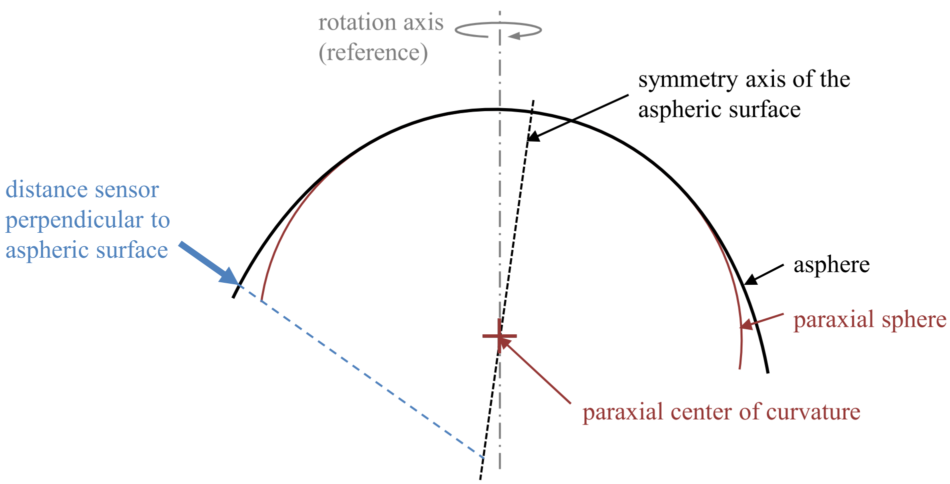

Figure 2: aspheric surface tilt measurement using a distance sensor

The distance sensor measurement is combined with the paraxial centration measurement to measure the asphere axis position and tilt. In addition to requiring the design data of the surface, the exact measuring position of the distance sensor has to be known. Previous systems using this measuring principle relied on manually positioning the sensor at a given offset from the lens edge. The repeatability of this method was limited not only by the skills of the operator, but also by the centration of the outer diameter of the lens. With measurement times for single lenses in the range of 10 to 20 minutes, the time-consuming, manual process was also not suited for production environments.

3. DESCRIPTION OF THE MEASUREMENT SYSTEM

To increase speed, accuracy and process safety of the asphere tilt measurement, manual alignment steps need to be automated. Our system therefore uses motorized mechanical stages in combination with live feedback from the individual measuring heads to automatically locate, align and measure the sample under test. The following chapters describe the setup as well as the measurement process in more detail.

3.1 System overview

The main components of the AspheroCheck UP system are shown in Figure 3. A rotational air bearing is used as the high precision reference axis of the system. A fully motorized tilt-and-shift table is mounted on the air bearing and enables automated sample alignment. By default, the sample under test is temporarily fixed to the alignment table using a ring chuck holder, and a low vacuum is applied to lock the lens position during measurement. Other solutions, such as self-centering holders or hydraulic expansion chucks for lenses on arbors, are also supported. To avoid any negative influences on the accuracy of the reference axis, no cables are connected to the rotating components: The motorized table receives both power and communication wirelessly over an air gap, and the vacuum is transported through the air bearing itself. Both air bearing and table feature an inner aperture, and the ring chuck holder is equipped with a glass window sealing the vacuum chamber to support measurement from both sides.

Two autocollimators featuring cross reticles, illuminated by high-power green LEDs are attached to the top and bottom of the system, with motorized stages moving the focusing head lenses vertically to the required positions. The head lenses are chosen in such a way to optimize either magnification or field of view, with a range of both positive and negative focal lengths extending the focusing range of both measuring heads. The lenses are installed automatically using motorized head lens turrets.

The distance sensor is positioned using two high precision linear stages with absolute encoders and sub-micron positioning accuracy, as well as rotary stage with high stiffness. The sensor is mounted off-center for direct positioning of the measuring range center, minimizing the influence of angular errors. This setup also maximizes sample diameter that can be measured with the system: With a horizontal travel of the sensor of more than 50mm starting at the center of the sample, the system supports samples with a diameter of up to 100mm. Positioning on one side of the sample is sufficient since the sample is rotated during measurement. The distance sensor itself is a miniature, non-contact confocal chromatic sensor attached using a kinematic mount. It can be swapped with a second measuring head featuring a 90° folding mirror that allows measuring bottom aspheric surfaces without the need to flip the sample.

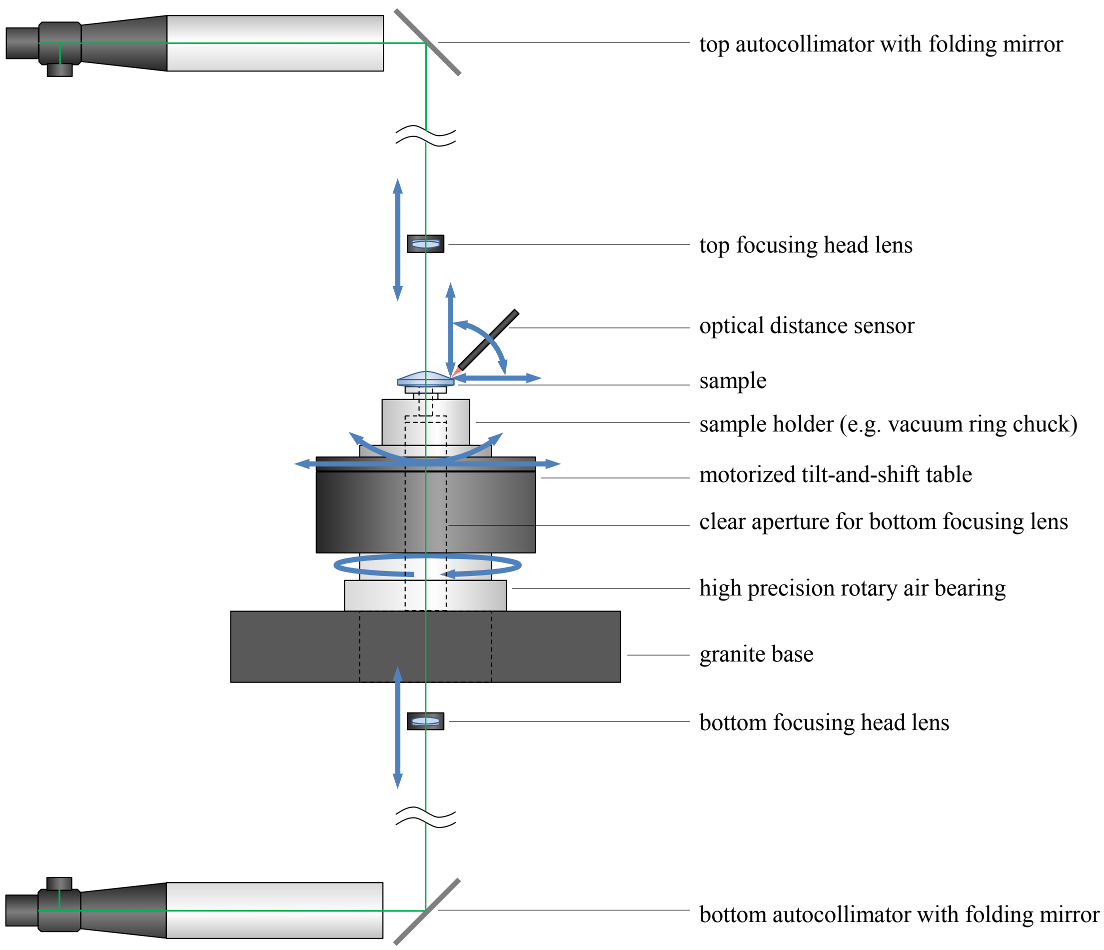

Figure 3: components of the AspheroCheck UP system

To enable absolute positioning of the sensor on the sample under test, the sensor position has to be calibrated with respect to the reference axis. This calibration is performed using a reflective calibration sphere with a known diameter, and includes measuring both the absolute offset of the positioning stages, and the relative offset between the pivot point of the sensor positioning stages and the center of the measuring range itself.

3.2 Measurement process

During the setup phase, the sample holder is installed and aligned using a plane parallel plate (tilt) and a reflective sphere (shift) in reflection mode. This pre-alignment ensures that the samples will already be pre-centered during measurement, and only needs to be performed once. The resulting alignment of the motorized tilt-and-shift table is stored as the home position.

The operator also enters the optical design of the sample into the software, including the polynomial definition of the aspheric surface, or imports this data from existing design files of other optical design software. The software uses this data to calculate the measuring positions for both measuring heads as well as the best measuring position for the distance sensor. Sensor-specific settings such as the shutter rate of the cameras can be set manually for each surface or will later be auto-adjusted during the measurement.

To measure a sample, the operator simply loads a process configuration and places the sample on the sample holder. The software will move the sample holder to the previously saved home position using the motorized tilt-and-shift table, then move the focal points of both measuring heads to the calculated positions and measure the centering errors of both surfaces using the technique described in chapter 2.1. After a single rotation, the current orientation of the optical axis of the sample is known, and the motorized tilt-and-shift table is used to align both (paraxial) centers of curvature to the rotation axis of the system. The remaining centering error of both surfaces is reduced to less than 0.2um in less than 10 seconds, using the live feedback from both measuring heads.

After alignment, the absolute position of the sample under test is known, and the distance sensor is positioned on the aspheric surface. Thanks to the encoders on both linear stages, the position error of the distance sensor is below 5um in all directions. The sample is then rotated again and the displacement of the aspheric surface is measured. Using the method described in chapter 2.2, the asphere axis tilt is calculated and the result is displayed. It is important to note that while the positioning accuracy is limited to several microns, the displacement at this position is still measured with the 0.1um accuracy of the distance sensor. For most aspheric surfaces, the conversion factor between measured displacement and asphere tilt is nearly constant over a range of a few microns, ensuring high repeatability of the process.

An overview of the full process is shown in Figure 4. Operator input is only required once during general system setup, and for the initial installation of the sample. All other measurement and alignment steps are performed automatically. The total cycle time for a single sample measurement is less than 1 minute including loading and unloading, making the process well-suited for large volume testing in production environments.

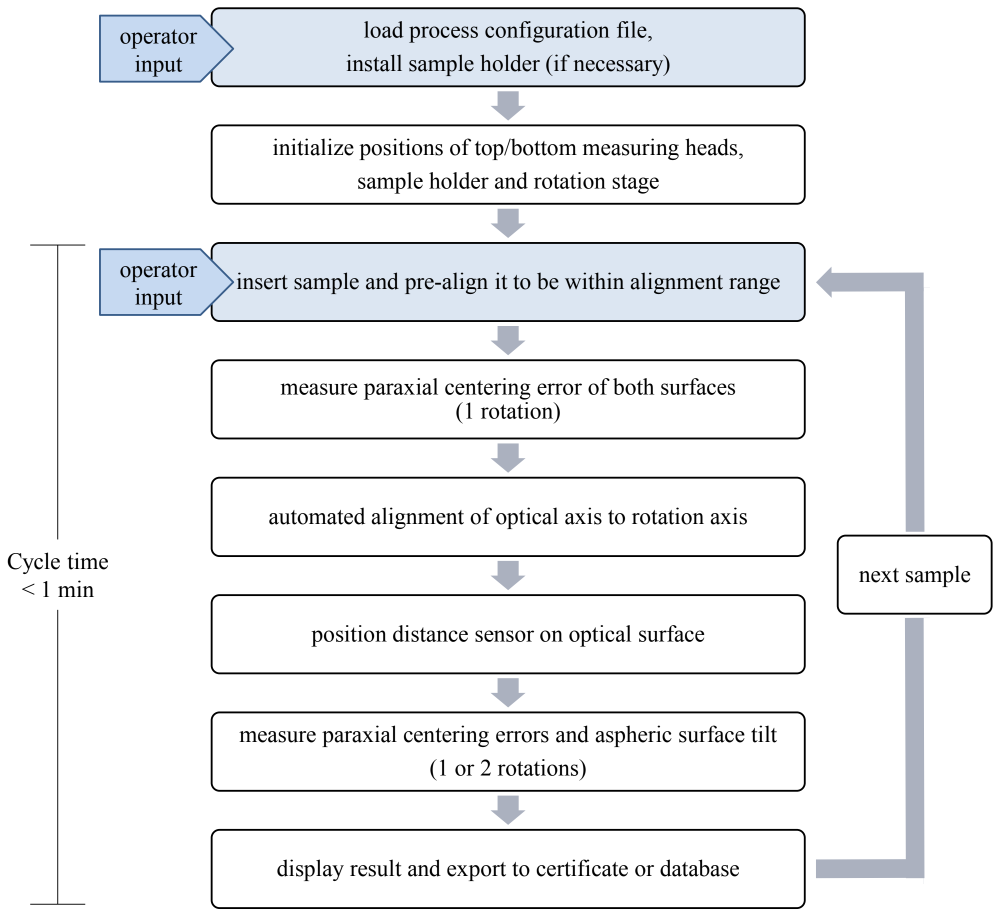

Figure 4: process flow overview

3.3 Additional measurement parameters

Since the distance sensor can be positioned freely along the contour of the sample, it is possible to access additional parameters. Outer diameter, flange or interlock surfaces can be included into the measurement without the need for cost-intensive modifications or expansions. The asphere axis orientation may then be expressed not only to the optical axis, but also to outer references or combinations of optical and reference surfaces.

If the sample diameter is large enough and the sample holder offers access to the bottom surface of the lens, aspheric bottom surfaces can also be measured using the distance sensor. For this purpose, the distance sensor measuring head may be exchanged with one that features a 90° folding mirror. Standard aspheres can thus be measured in reversed orientation, which may be of importance depending on the way the lens is mounted. A double-aspheric lens can also be fully characterized without the need to flip the sample during the measurement process, eliminating time-consuming referencing and alignment tasks.

For samples where the aspheric surface does not follow the nominal design closely, the asphere tilt measurement may be performed at multiple positions along the surface. The results from the individual zones may then be used to analyze the type of shape deviation present, or averaged to increase the stability of the measurement. The latter is especially useful for samples where the aspheric shape results in a low sensitivity, see chapter 2.2.

4. MEASUREMENT RESULTS

The following results were recorded using a biconvex sample lens with a clear aperture of 22.5mm of the aspheric surface. The sample was held using the standard ring chuck holder with a vacuum of -0.1 bar applied to hold the sample.

The sensor was positioned at a variety of positions along the surface, indicated by the normalized pupil coordinates, where R is the semi-aperture of the sample. The conversion factor was in the range of 0.9 to 1.2 arcmin per µm.

At each position, five independent measurements including the automatic alignment of the optical axis were performed. The table below contains the mean values and standard deviations for each zone as well as the overall statistic for all measurements:

pupil coordinate	optical axis vs. rotation axis		asphere axis vs. optical axis			
[-]	tilt [arcmin]		tilt [arcmin]		shift at vertex [µm]	
h / R	mean value	standard dev.	mean value	standard dev.	mean value	standard dev.
0.90	0.013	0.004	1.726	0.017	30.9	0.3
0.92	0.024	0.003	1.750	0.026	31.4	0.5
0.94	0.011	0.004	1.782	0.037	31.9	0.7
0.96	0.011	0.002	1.775	0.044	31.8	0.8
0.98	0.017	0.007	1.754	0.018	31.4	0.3
0.99	0.011	0.003	1.738	0.018	31.1	0.3
all	0.014	0.006	1.754	0.035	31.3	0.7

Table 1: Measurement results for a sample aspheric lens

The automatic alignment procedure reduced the optical axis tilt in all measurements to below 2 arcsec. This illustrates the precise alignment that is faster and more reliable than the manual process previously needed for this type of process. The measured asphere axis tilt averaged around 1.75 arcmin for this sample, equivalent to a shift between the asphere axis and the optical axis of around 31 µm at the vertex of the aspheric surface. The standard deviation over all 30 measurements was only 2 arcsec for tilt and 0.7 µm for shift, illustrating the high measurement accuracy possible with AspheroCheck UP.

The results from the individual radial position can be compared to further examine the aspheric surface: Local surface defects influence the measured value and standard deviation of a single zone, whereas overall shape errors are indicated by varying results across all measuring positions.

5. CONCLUSION

We present a novel metrology system that improves on the existing process for measuring the centration of aspheres by means of automation and precision controlling. Thanks to the fully automated process, the cycle time per samples is reduced to less than one minute including loading and unloading, making the process ideally suited for high-volume testing in production environments. Initial results demonstrate a significantly improved accuracy of the measurement. Due to the layout of the measurement instrument, the process can easily be adapted to include mechanical references, various surface types and advanced topography analysis by extending the capabilities of the software.

REFERENCES

[1] Trioptics AspheroCheck UP: https://www.trioptics.com/products/systems-for-optical-centration-measurement-and- alignment/asphercheck-up

[2] Heinisch, J., Dumitrescu, E. and Krey, S., "Novel technique for measurement of centration errors of complex completely mounted multi-element objective lenses," Proc. SPIE 6288, Current Developments in Lens Design and Optical Engineering VII, 628810 (01 September 2006)

[3] Heinisch, J., Krey, S. and Dumitrescu, E., "Verfahren zur Messung optischer Oberflächen innerhalb einer mehrlinsigen Anordnung," Patent DE102004029735C5 (15 September 2011)

[4] Henisch, J. and Dumitrescu, E., "Method and device for determining the position of the symmetrical axis of an aspherical lens surface", Patent EP1918687B1 (07 September 2011)