Quality Assurance of Modern Optics in Production

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1. Introduction

The rapid introduction of miniaturized digital camera technology in daily life with continuously increasing optical resolution puts high demands on the manufacturing quality of the lenses and on the tolerances in the assembly. In most cases the miniaturization requires the use of aspherical elements with even higher demands on the manufacturing of the optical surfaces and on the centering inside the optical system. In parallel the high volume production of consumer optics or in the automotive industry asks for fast test systems allowing 100% testing in short cycle times. This paper presents new measurement techniques for the quality assessment of individual lenses and complete lens assemblies. Centering errors are identified as the primary cause for limiting the optical performance. A new method for measuring the centering error of aspherical lenses is described. The overall centering can be improved by making precisely centered sub-assemblies by means of lens barrel turning or automatic alignment and glue bonding in a barrel. Wavefront sensing is introduced as a method for the rapid characterization of the next generation wafer level lenses. The measurement of the modulation transfer function has become the industry standard for the final imaging quality assessment of complete lens assemblies and imaging modules even for low-cost optics.

2. Lens centering

The continuous miniaturization of lens systems especially in consumer optics results in centering tolerances that have been found so far only in costly microscope

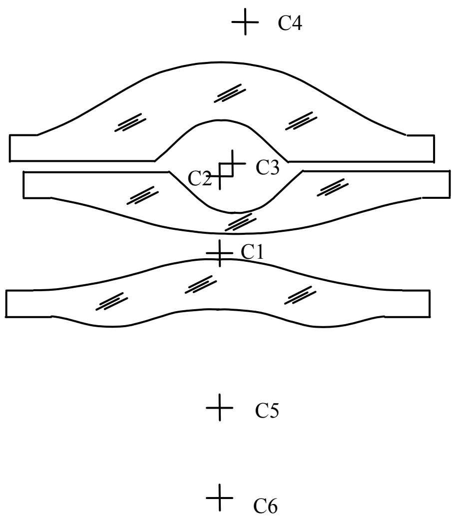

Figure 1: Lens centering errors are the primary cause for poor imaging quality. C1..C6 denote the non-aligned paraxial centers of curvature of the surfaces.

objectives or other professional equipment. Tolerances below 5 micron are common even in a few cent item like a mobile phone lens. This tolerance must be kept during the automatic high volume production and by using low-cost materials. While the surface quality of the typically plastic molded lenses is often sufficient, centering errors are the major cause of poor imaging quality. Centering errors are traditionally measured with an autocollimation telescope in reflection giving the surface tilt error or the displacement of the surface center of curvature from a reference axis. For many years this technique has been on the market for characterizing single lenses and the cementing of doublets. It has now become also available for the characterization of completely assembled objective lenses with a high number of optical surfaces [1]. The PC assisted instrument performs stepwise a centering measurement starting with the first surface closest to the autocollimator and continuing with the next surfaces. The refracting properties and the measured centering error of each prior surface are taken into account by measuring the following surface. The PC performs a ray tracing through the objective lens based on the lens design parameters and the measured centering values. Finally, the operator obtains a numerical and graphical output of the complete centering status regarding shift and tilt of each measured surface. The measurement is based on the precise rotation of the sample with an air bearing having a run-out error less than 50 nm. Initially, all results are referred to this rotary axis, but can be easily transferred to a different reference system, e.g. a best-fit axis through all optical groups, a best-fit axis defined by a significant group, or an axis defined by the housing symmetry or some mechanical reference surfaces.

The usual method of making a precisely centered lens assembly is based on the making of precise sub-assemblies which are later combined into a mechanically tightly toleranced barrel. This procedure is based on the fact that mechanical manufacturing and tolerancing is better controlled than the optical counterpart. The sub-assemblies are obtained by barrel turning or the automatic centering and glue bonding in a barrel. For barrel turning the optics is mounted more or less carelessly into an oversized barrel. The barrel is then adjusted in a special alignment chuck so that the optical axis aligns with the rotary axis of the turning machine. Afterwards the barrel is turned to the final size including the reference surfaces well aligned to the optical axis. Barrel turning is the more expensive method but gives the highest quality and is usually applied for precision optics. The automatic alignment and gluing into the barrel is more often applied for consumer optics.

Miniaturized high resolution lenses often require one ore more aspherical elements which put even higher demands on the system's centering and its measurement. Aspherical lenses cannot be completely centered by alignment inside the system, but must be intrinsically centered during the manufacturing and carefully assessed before implementing them into the optical system. For this purpose, the standard autocollimation test method has been complemented with an additional high resolution sensor to be able to measure the orientation of the asphere axis referred to the paraxial optical axis or to mechanical references of the lens. The additional sensor is a chromatic confocal distance probe having a few nanometer distance resolution. It measures the usually small run-out at the edge of the asphere, while the autocollimator measures the paraxial region. From the combined results, the tilt of the asphere axis is calculated.

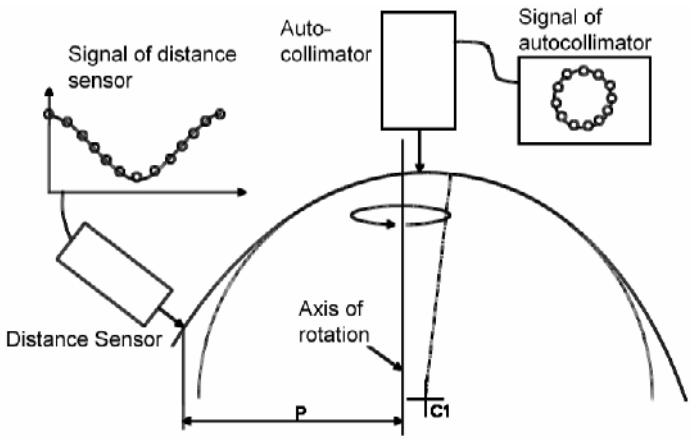

Figure 2: Principle of asphere axis measurement using a distance probe measuring the edge run-out of an asphere.

2. Image quality assurance

The final assessment of the imaging quality of a completely assembled objective lens or imaging module is usually done by measuring the modulation transfer function (MTF) at different image field heights according ISO 9334. This is nowadays also true for low-cost commercial optics where not standardized test chart inspection proved to be not comparable between supplier and system builder. However, the used MTF test benches for in-line production have greatly changed compared to their laboratory counterparts. They usually employ the reverse imaging scheme which essentially allows faster measurement cycle times compared to the classical forward imaging. In the reverse imaging method an illuminated test chart reticule is brought into the focal plane of the sample which projects images of the test structures into the entrance pupils of several camera equipped telescopes at different field angles. This setup allows the simultaneous and thus fast measurement at different field angles at the cost of multiple image analyzers. No moving stages are required for accessing and measuring the different fields. There is an intrinsic image magnification given by the ratio of telescope and sample focal length, thus no high quality, high-NA relay lens is necessary. Latest instruments allow the rapid image quality measurement at 9 image field positions within 2 seconds including a focusing scan.

3. New Developments

The above lens characterization can only be applied for complete and thus well corrected objective lenses. Of coarse the constituent single lenses have to be characterized, too. Even in the fully automated process for the low-cost mass market it is required to sort out the poor lenses to avoid combining them with the costly image sensor. The traditional lens characterization includes amongst others the centering measurement and the surface quality testing. The first one is a time consuming method and can only be done random wise or in the prototyping phase. The second is an open issue when it comes to aspherical surfaces. There is not yet any established method that allows the in-line surface form characterization of aspheres. Interferometry methods fail due to the huge asphericity that is usually found. Computer generated hologram (CGH) assisted interferometry is avoided because of the cost of the CGHs, the large number of asphere designs and their short life time in the rapidly changing consumer market. Point wise scanning methods fail due to their low speed. Two promising approaches are discussed. The first one is the asphere characterization and adaptive correction during the manufacturing [2], and the second is the wavefront measurement. Both apply to different application fields. The adaptive manufacturing is useful where each asphere is individually machined without any replication process. The manufacturing time is reduced by the on-machine measurement avoiding time consuming measurement and correction cycles. The wavefront measurement is currently applied in the high volume lens production, especially of wafer level lenses [3]. Though it is not a single surface form measurement, it gives yet valuable information about the overall and local form accuracy within the frame rate of a CCD camera. The method takes advantage of the large wavefront dynamic range of a Shack-Hartmann based wavefront sensor compared to interferometers. A major disadvantage is that not an individual surface is measured, but the combined effect of both surfaces in transmission. The reflective measurement on a single surface is currently investigated.

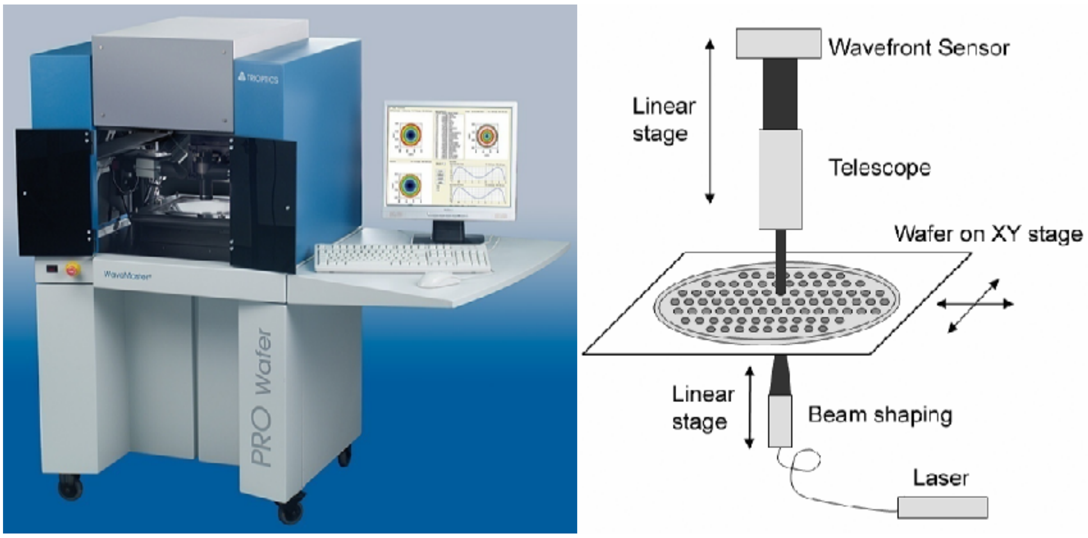

Figure 3: Wavefront sensor based system for measuring wafer level lenses.

References

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