Highest Precision Centering Error Measurement

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ABSTRACT

The optical imaging quality of objectives is mainly influenced by the errors of the mechanical alignment of the single elements. TRIOPTICS has developed a new technology called MultiLens® in order to measure the centering error of single lenses as well as complete objectives. It is possible to measure the tilt of each single optical surface inside of a mounted objective with highest precision. We achieve accuracies in the range of an arc second. During the measurement the deviation of each centre of curvature with respect to a reference axis is measured. These data are further processed in order to provide the shift and tilt of an individual lens or group of lenses with respect to a given reference axis. The knowledge of the centering error can be used to align actively single optical elements.

Applications mainly include the measurement of cell phone and digital camera lenses. However, any type of objective lens from endoscope up to very complex objective lenses used in microlithography can be measured with highest accuracy.

Keywords: centering error, lens, optical surface, objective, aspherical axis

1. INTRODUCTION

The knowledge of the true centering error of individual optical surfaces inside of a mounted objective is becoming an important factor for the manufacturing of high quality miniature optics. TRIOPTICS developed a measurement device to measure the individual centering errors of completely assembled optics. Based on these measurements it is possible to calculate the shift and tilt of different optical elements with respect to a given reference axis. The reference axis can be a mechanical axis (sample mount), it can be a best fit axis through all centres of curvature or it can be the optical axis of a single optical element.

The measurement is made on a vertical optical bench. The sample is placed on a high precision air bearing. The reference axis for all measurements is given by the axis of rotation. Therefore a high precision air bearing is used to provide a reference axis with a run out below 0.05µm. The basic measurement results are provided with respect to this axis of rotation.

1.1 Principle of measurement

For the measurement of the centring error an electronic autocollimator is used for non contact measurement. This autocollimator is equipped with a set of focusing optics to provide a wide focusing range. In case the light emerging from the autocollimator enters the surface under test almost perpendicular a fraction of light will be reflected back. This happens when the focus point of the focusing autocollimator reaches the plane of curvature of the surface under test. The light will be focused on a CCD-camera. An image of the autocollimator target (usually a cross hair) can be found. If the surface is tilted with respect to the axis of rotation the image of the cross will be shifted. This can be seen when turning the sample around the axis of rotation. In this case the cross hair image turns on a circle. The diameter of the circle is related to the tilt of the surface (see Fig. 1).

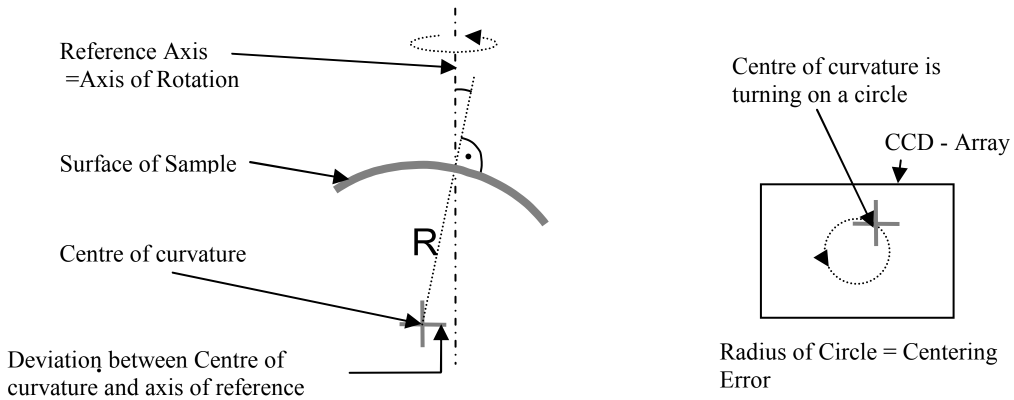

Fig. 1. A spherical surface is tilted with respect to the axis of rotation. By use of a focusing electronic autocollimator the center of curvature can be visualized on a CCD by using an illuminated cross hair target. While rotating the sample the image of the cross hair target moves on a circle. The diameter of the circle is proportional to the tilt of sphere.

This is valid for single surfaces. If the sphere under test is inside of an optical system the measurement has to take care about other surfaces within the optical path. To get an image of the target, the light entering the surface under test has to be almost perpendicular. This is the same condition as before. But now the focusing autocollimator has to focus into a different plane. Due to refraction of surfaces in front of the surface under test the image of the centre of curvature will be shifted to a different plane. This position can be easily calculated if the basic parameters of the sample (like: curvature, refractive index and thickness) are known. But also the centering error of surfaces in front of the surface under test influences the measurement result. Because the design parameter of the sample are known, and because the centering error of the first surface can be measured directly the true centering error of the second surface can be calculated too. After the error of the second surface is known the third can be calculated and so on. It is possible to measure up to 30 surfaces in this way.

After the measurement is finished, the true cartesian coordinates of all centers of curvatures with respect to the coordinate system of the measurement device can be calculated (Fig. 2a). This set of data can be further used for a more detailed analysis of the sample.

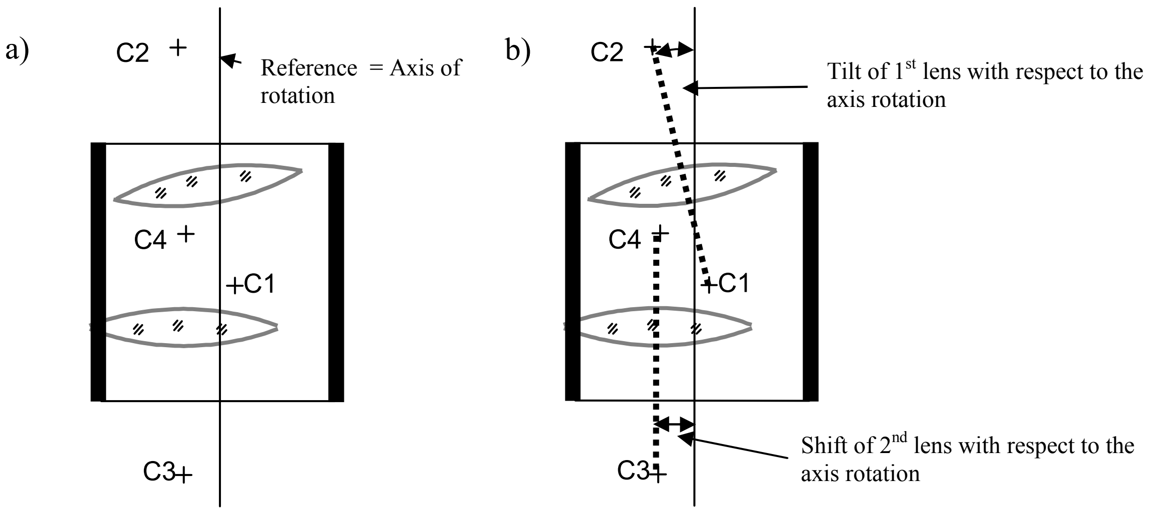

Fig. 2. The diagram shows an optical system consisting of two singlets. a) The measurement result provides the centers of curvature of each surface (indicated by “C” and number of surface). The optical axis of each lens results as a connection of the centers of curvature. b) Now tilt and shift of each single lens in respect to the reference axis can be calculated.

After calculating the cartesian coordinates of the set of centre of curvatures, it is possible to fit a line connecting the centres of curvature. E.g. if the first lens is a singlet, a line can be drawn through the centre of curvatures of surface one and surface two. This line refers to the optical axis of the first lens (see following figure). The procedure can be continued with other lenses or groups of lenses too. Now it is possible to calculate the shift or the tilt of this lens or group of lenses with respect to different references: the reference can be the axis of rotation (see figure 3b), the mechanical axis a lens mount, a reference surface of a lens mount, etc. The figure shows the definition of the shift and tilt of the lenses. Figure 4 shows the shift and tilt of lens 2 with respect to lens 1.The reference can also be the axis of the mechanical lens mount. In this case an electronic indicator is used to measure the axis of the mount in respect to the axis of rotation.

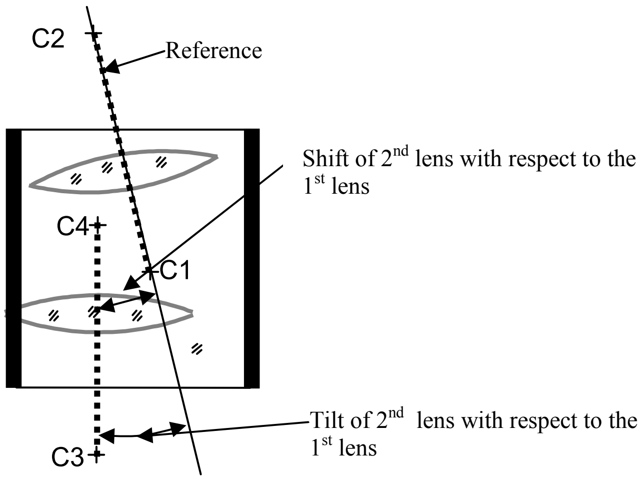

Fig. 3. Shift and Tilt of lens #2 in respect to lens #1.

2. MEASUREMENT RESULTS

For a typical measurement, an objective consisting of two doublets has been selected. See Fig. 7.

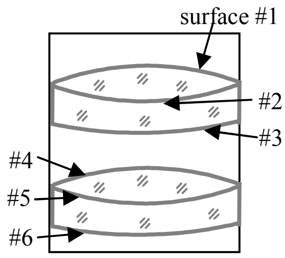

Fig. 4. Sketch of the sample used for measurement. Two similar doublets are mounted together in a housing.

The sample has been measured 4 times. After each single measurement the sample has been removed, turned around the azimuth (approx. 90°) and placed again on the air bearing. Due to this procedure the centering error results of each measurement in respect to air bearing are quite different. The raw data can be, however, used for the calculation of the Cartesian coordinates of the centres of curvature (as shown above), for definition of the optical axes of the optical elements and finally to unveil the centering properties of the sample.

For this purpose, a fit line was generated through the first doublet, a second separate fit line through the second doublet. Eventually the tilt and shift of these fit lines have been calculated, as given in the table. The calculation has been made for all 4 measurements. Column 4 shows the shift between the first and the second doublet and column #7 shows the tilt between both doublets. From the x and y component of the shift it can be also seen that the sample has been turned clockwise roughly around 90° between the single measurements.

This can be seen in the following table of data.

Table 1. Shift and tilt of the first doublet in respect to the second doublet:

No. Measure.	**Shift X [µm]**	**Shift Y [µm]**	**Shift Total [µm]**	**Tilt X [arcmin]**	**Tilt Y [arcmin]**	**Tilt Total[arcmin]**
1	1.7961	-8.4130	**8.6026**	0.2644	4.0365	**4.0452**
2	-8.770	-1.8986	**8.9736**	4.0548	-0.0833	**4.0557**
3	-0.8953	8.7743	**8.8199**	-0.3458	-4.0351	**4.0498**
4	8.4513	1.9539	**8.6742**	-4.0579	0.0587	**4.0584**
Average			**8.768**			**4.052**
Std.Dev.			**0.164**			**0.006**

The data above illustrate the high accuracy and repeatability of the measurement. The shift between both doublets is 8.77µm with a standard deviation of 0.16µm. The tilt between the optical axis of both achromats is 4.05 arc minutes measured with a standard deviation of 0.006 arcmin (0.4 arcsec!).

REFERENCES

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