# Measurement of centering errors, automated adjustment and mounting of lenses

BY JOSEF HEINISCH, TRIOPTICS GMBH

*Classical optical measurement techniques combined with modern PC technology provide accurate alignment, bonding and cementing of optical components and systems. These processes are fully automated and significantly reduce production time and cost.*

The processes involved in manufacturing optical lenses – grinding, polishing and coating – have become increasingly automated in the past few decades. Computer numerical controlled grinding and polishing machines, as well as computer-controlled interferometers for the examination of the surface profile, are in widespread use.

However, many lens manufacturers still use simple optical or tactile measurement instruments for determining centering errors. More often than not, the lenses are still adjusted manually. The adjustment and centering errors of the optical components have a decisive influence on the image quality of the lens. The use of electronic autocollimators and automated adjustment equipment makes the mounting process quicker and more precise – for example, when cementing achromatic lenses or bonding lenses into a mount.

## Centration error measurement

When measuring a centering error using the reflection mode (Figure 1), an electronic autocollimator, read via a PC, is at the core of the measurement. An illuminated target (usually a reticule) is projected at the center of curvature of the spherical or almost spherical lens surface under investigation. In this instance, the rays of light meet the surface at an almost perpendicular angle. Some of the light is reflected back along the exact path it came (a condition of autocollimation) and displays the target on a CCD camera. A lateral shift of the center of curvature creates a direct lateral shift of the reticule image.

If the surface under investigation is rotated around a reference axis, a corresponding circular movement of the reticule image is created on the CCD sensor. The radius of this circular path is directly proportional to the position of the center of curvature in relation to the reference axis. The live reticule image depicts the exact position of the center of curvature in the X-Y axis, whereby the center of the circular path represents a reference point in the overall space. Powerful light sources and light-sensitive CCD sensors ensure that even test items that are well antireflection-coated produce a sufficient autocollimation image.

In extreme cases, it is also possible to

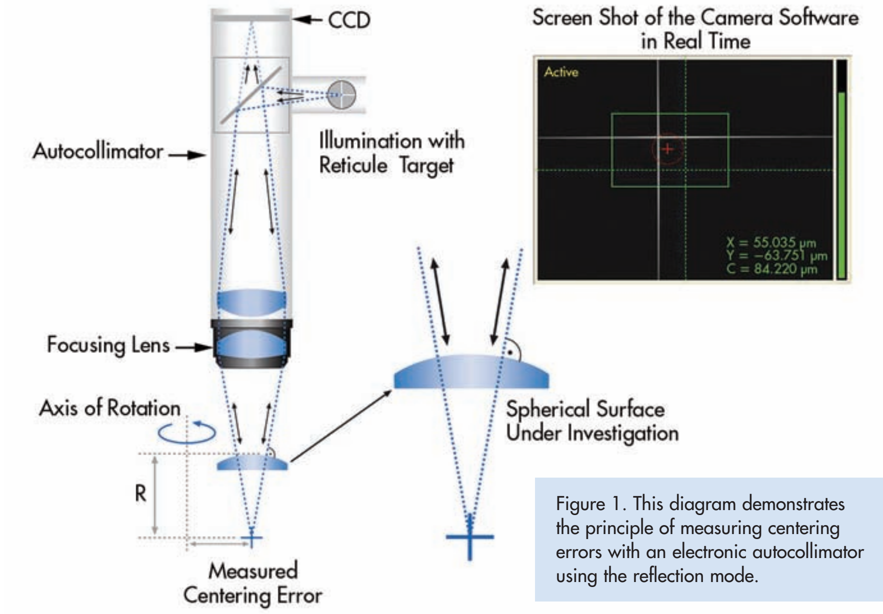
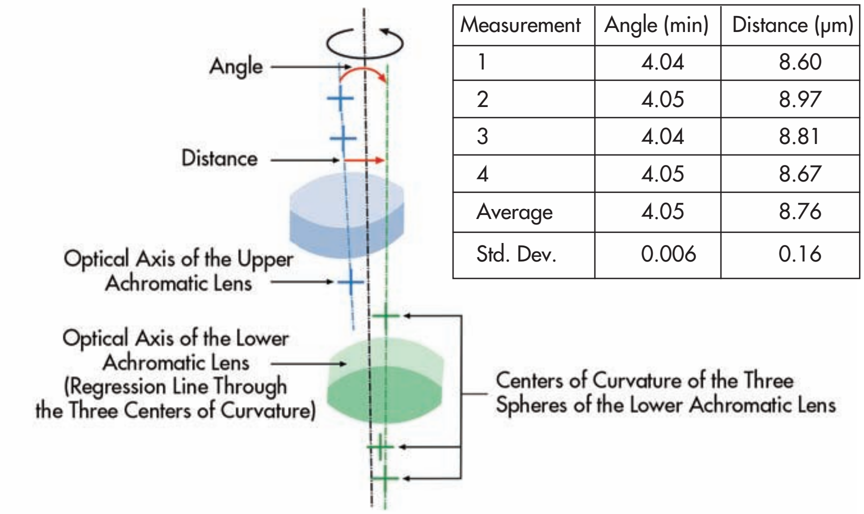


Figure 1. This diagram demonstrates the principle of measuring centering errors with an electronic autocollimator using the reflection mode.



| Measurement | Angle (min) | Distance (μm) |
|---|---|---|
| 1 | 4.04 | 8.60 |
| 2 | 4.05 | 8.97 |
| 3 | 4.04 | 8.81 |
| 4 | 4.05 | 8.67 |
| Average | 4.05 | 8.76 |
| Std. Dev. | 0.006 | 0.16 |

Figure 2: Measurement of the angle and the distance of the optical axes of the lenses to each other.

**Reprinted from the June/July 2010 issue of** EuroPhotonics © **Laurin Publishing Co. Inc.**

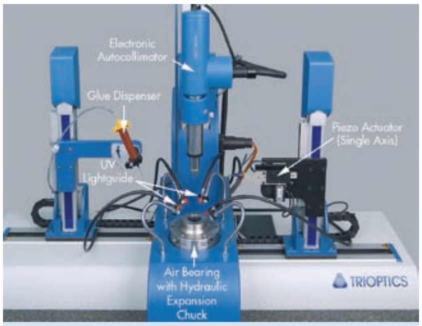


Figure 4. The frontal view is shown of an automated centering and bonding station for the assembly of lenses into a mount.

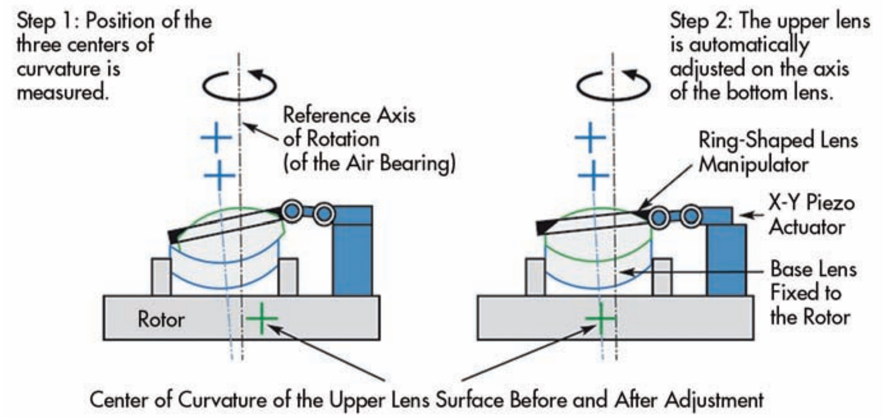


Figure 3. The multilens measurement method is used for the automated adjustment of achromatic lenses in the cementing process.

carry out the measurement using near-infrared (750- to 1000-nm) illumination. In this spectral range, the antireflection coatings optimized for the visible range have enough reflectivity. As an alternative to incoherent light sources, laser autocollimators are available, although these can produce images that are difficult to interpret due to speckling.

## Centration error measurement of objectives

The effectiveness of measuring centering errors with an electronic autocollimator in combination with computers is apparent when measuring multiple lenses.[1] This method identifies the centering error of each individual lens surface in a mounted optical assembly. Any selected axis of rotation serves as a reference axis. Suitably precise air bearings with radial and axial runout errors of <0.05 µm are available.

First, the centering error of the outermost optical surface is measured in relation to the axis of rotation. The next step is to focus in to the center of curvature of the second optical surface. For the calculation of the position of the center of curvature (Z), the optical properties of the first outermost surface must be taken into account. When evaluating the true centering error (X, Y) of the second surface using optical calculations, it is also necessary to take into consideration both the optical properties and the centering error of the first surface previously measured. This calculation simply requires the design data (radius, center thickness, refractive index) of the item under investigation. When the exact centering error of the second surface has been identified, the centering error of the third surface can be measured, and so on. This measurement process has proved itself to be extremely robust.

Using design data alone is more than suitable for the evaluation, as it is unusual for a significant difference to exist between that data and actual lens measurements. In practice, it is possible to gauge with a single autocollimator the positioning errors of 20 or more surfaces to an exactness of <1 µm. To clarify the effectiveness of this measurement process, Figure 2 shows the measurement results of an optical assembly. The sample assembly consists of two identical achromatic lenses with surface radii in the region of 40 to 120 mm. The multiple-lens measurement provides the exact position of all the centers of curvature in relation to the rotational axis. Since an achromatic system consists of three optical surfaces, the optical axis of a single achromatic lens can be displayed via a regression line through the three centers of curvature. This is indicated by the dotted blue and green lines in Figure 2.

If the optical axes are known, it is possible to define the angle and distance between both optical axes (here in the plane of the upper vertex). These calculations are automatically executed as part of the

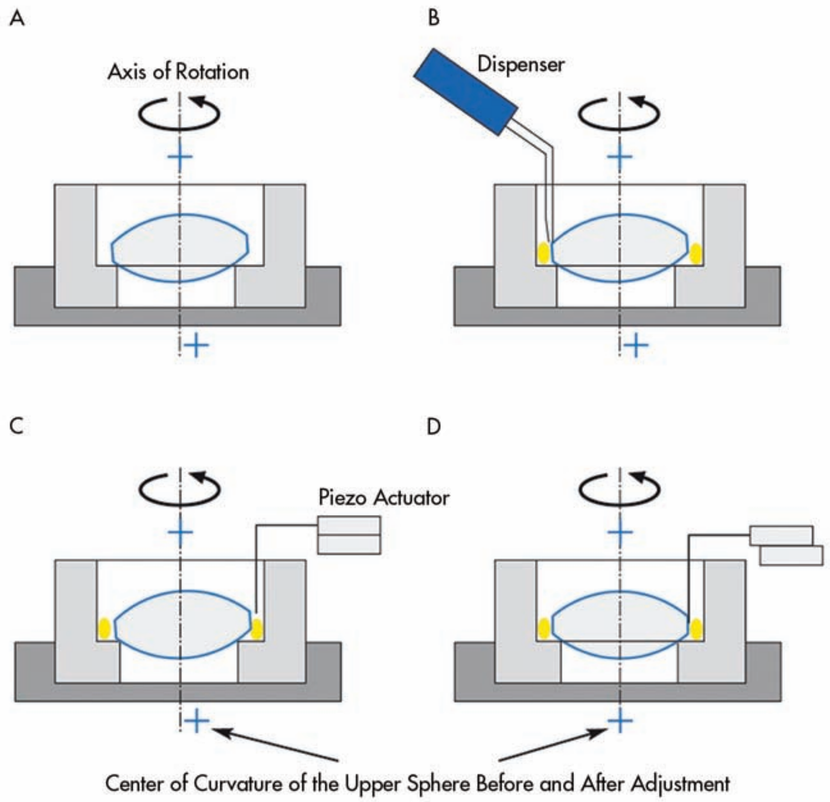


Figure 5. Panels A to D show the step-by-step process of automatically bonding a lens into a mount.

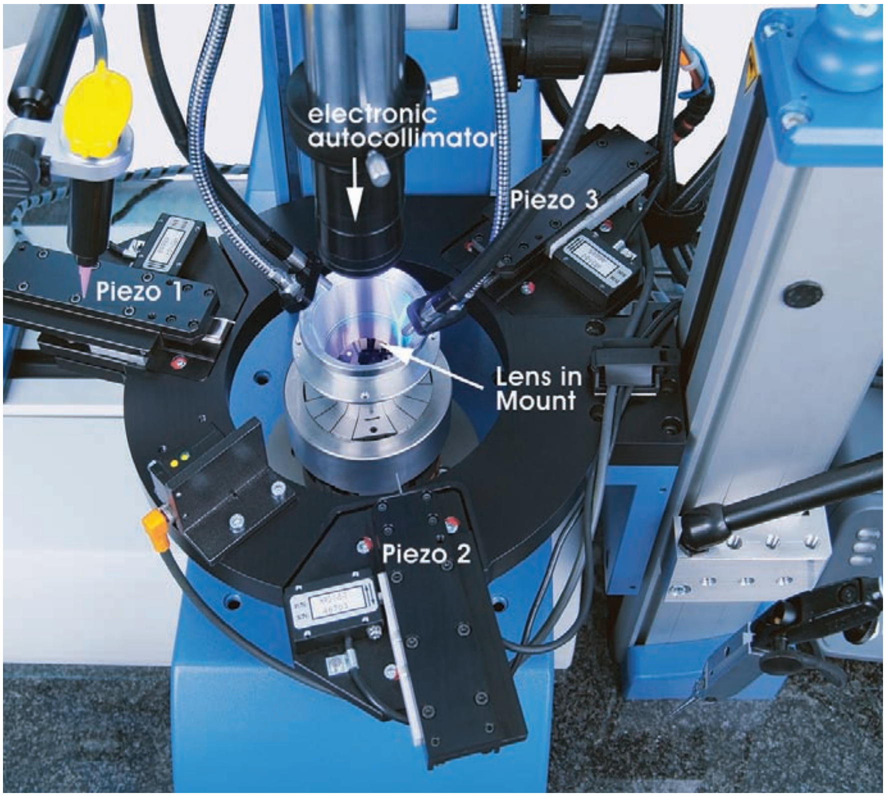


Figure 6. Pictured is an automated bonding station with three piezo actuators.

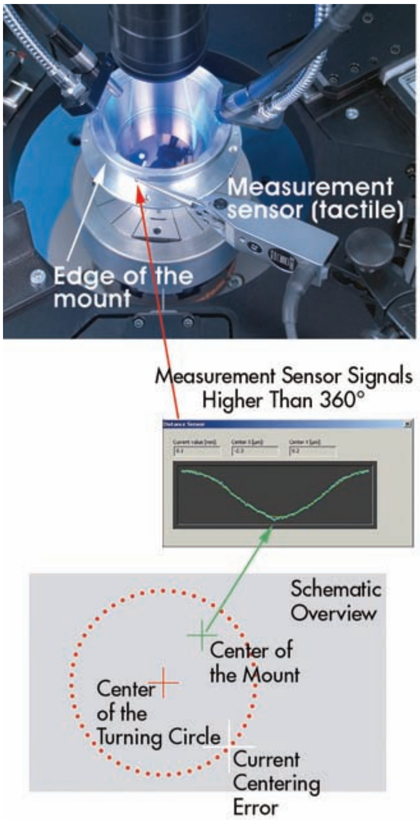


Figure 7. The center of the mount's circumference can be identified using an additional measurement sensor. The lens is positioned using three needles (set apart from one another at a 120° angle) and adjusted to the center of the mount.

measurement process. The results are shown in Figure 2. The multiple-lens measurement of the objective has been carried out four times. After each measurement, the item under investigation was removed from the bearing and, without any particular provisions, replaced for the next (measurement at a 90° azimuth angle). The result is a standard deviation of 0.16 µm in the distance measurement of both optical axes.

If the exact positions (X, Y, Z) of all centers of curvature are known in a fixed system of coordinates, this information may be used to optimize the optical assembly. In the example given here, the upper achromatic lens can be realigned by the previously measured magnitude of 8.8 µm in the direction of the optical axis of the lower lens (green line).

## Automated cementing of achromatic lenses

There is a new process for adjusting two single lenses of an achromatic lens.[2] Based on the multiple lens method, it does away with the precise initial adjustment of both lenses. Instead, the exact position of each of the three centers of curvature is identified in its uncemented state. The axis of rotation of a highly accurate bearing serves as a reference axis for the measurement of the centering error, but not as a reference axis for the adjustment. Hence there is no need for precise, self-centering mechanical holders. Both lenses are fixed to the rotor of the bearing, and their center remains unaltered throughout the measurement process. The cement between the lenses is still fluid at this point.

Once the centering error has been measured, the center of curvature of the upper sphere is adjusted according to the optical axis of the lower lens. A ring-shaped support, fitted with an X-Y piezo actuator, is placed on the upper lens. It moves the upper lens so that all three centers of curvature eventually lie on the one line, the optical axis (Figure 3). The cement is then hardened using UV light. The entire measurement and adjustment cycle lasts only 10 to 15 seconds. This method is five to 10 times more accurate than the manual process and is particularly effective in the production of small optical components with 1-mm diameters – endoscopes, for example.

## Automated bonding of lenses into a mount

When bonding lenses and optical elements into a mount, the optical axes of these elements must be brought into line with the axis of the mount itself. The axis of the mount can be given in terms of the symmetrical axis of a cylindrical mount. An instrument for the precise alignment and bonding is shown in Figure 4.

Figure 5 is a schematic representation of the basic process. The workpiece (mount with unglued lens) is positioned on the rotor of a rotational axis. The mount's support has previously been aligned to the axis of rotation to a degree of accuracy of 2 µm. A so-called hydraulic expansion chuck is used as the support, which can transfer the center accuracy almost perfectly to the lens mount.

Before the centering error is measured, a robot arm moves in with a dispenser of UV-curable glue. The glue is applied to the lens and the mount by rotating the test item 360°. The centering error of the upper lens surface is now determined using the autocollimator.

Since the mount and therefore also the ring-shaped face of the lower lens surface are centered perfectly with respect to the axis of rotation, it is sufficient to center the upper surface. To achieve this, a manipulator is introduced on another robot arm. The manipulator may be fitted with either a single-axis piezo actuator (Figure 4) or with three single-axis piezo actuators (Figure 6), which are fixed at 120° from one another on a ring. In the instance where only one actuator is used, the test item must be rotated before the final adjustment in such a way that the axis of rotation, the center of curvature and the piezo axis are all on the same line. If three actuators are used, the lens can be adjusted on the center of rotation without rotating the sample again.

The accuracy of the adjustment can be increased by taking an additional measurement of the position of the mount's axis. A linear measuring sensor (resolution 0.1 µm) is placed on the edge of the mount (Figure 7) and takes measurements over a 360° rotation. The results are presented using a sine curve that identifies the X-Y coordinates (centering error) of the mount. Using the piezo actuators, the lens can now be adjusted to the direct center of the mount (green cross in Figure 7).

Once the lens has been successfully adjusted, the glue can be hardened by switching on a UV light source. The advantage of such a process is that the lens can be adjusted with great exactness on the mount, without the mount itself having to be perfectly adjusted to the axis of rotation. The multiple-lens measurement described here, the cementing of achromatic lenses and the gluing of lenses are perfect examples of the advantages of a computer-aided measurement of centering errors.

The previously laborious and therefore expensive form of adjustment has been simplified by intelligent measurement technology. The consistent use of this technology enables a greater degree of accuracy in the production of optical systems and therefore new design opportunities for more compact and higher-quality lenses.

## Meet the author

Josef Heinisch is a physicist at Trioptics GmbH in Wedel, Germany; e-mail: j.heinisch@trioptics.com.

## References

1. Verfahren zur Messung optischer Oberflächen innerhalb einer mehrlinsigen Anordnung. Patent Application 10 2004 029 735.5-51, German Patent Office.
2. Verfahren zur Herstellung con Systemen zusammengesetzter Linsen. Patent Application 10 2005 013 755.5, German Patent Office.