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Rotation-free industrial alignment of high performance optics

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Abstract. Conventional production methods for high precision lens alignment typically rely on lens rotation. In the case of rotationally non-symmetric optics and mounts, this is problematic. Here, we report a new concept for alignment bonding without lens rotation, based on a high precision linear bearing as position reference and a hexapod actuator for lens manipulation. For the optical axis of two test lenses after bonding, <1 arcmin element tilt and <10 µm decentre was achieved. This is confirmed by an independent measurement. Our alignment device and process can be applied for any lens and mount geometry. This will be especially useful for high-end products with small size and for rotationally non-symmetric systems.

1 Conventional lens alignment

The assembly of high performance imaging lens systems requires extreme accuracy. Lens tilt below 2‘ and decentre below 10µm cannot be achieved by mechanical positioning, due to machining tolerances. For this reason, alignment turning processes are widely used for industrial production of high performance lenses [1]. This involves the mounting of each lens in a subcell and the subsequent adaptation of the mechanical interfaces to the optical axis of the lens by use of a turning machine with integrated optical measurement instruments. Finally, each subcell is integrated in the optical system.

1.1 Limitations

Inherent disadvantages of alignment turning include:

- It is not suitable for rotationally non-symmetric lenses and mounts
- Alignment precision is determined by the used turning machines for the subcells and also by the mechanical tolerances of the main mount
- The double mounting is space consuming

In medical imaging, for example, these limitations are highly relevant. Endoscopic devices must be small and do not allow for subcell mounting. Large optics with flat sides (for stereoscopic imaging), or prisms cannot be processed. Alignment of lens systems requiring separate mounts (e.g. zoomsystems), remains complicated.

2 New alignment device

In optical terms, the lens position is defined by the centres of curvature of both optical surfaces. The line through these centres is called the lens's optical axis. The position of optical surfaces can be measured by an autocollimator [2]. For alignment turning, the optical axis is made to coincide with the well-defined rotation axis, using the lens's rotational invariance.

In contrast, we use the axis of an autocollimator's linear bearing as reference. Furthermore, we use a hexapod actuator to tilt the lens about the centre of curvature, which is the point of rotational invariance in all directions, of the first lens surface. The lens is aligned and bonded directly in the optical system, avoiding any further position tolerances.

2.1. Process description

The optical surface positions are measured by an autocollimator on a high precision linear bearing. For curved surfaces, a head lens is attached, see **Fig. 1**.

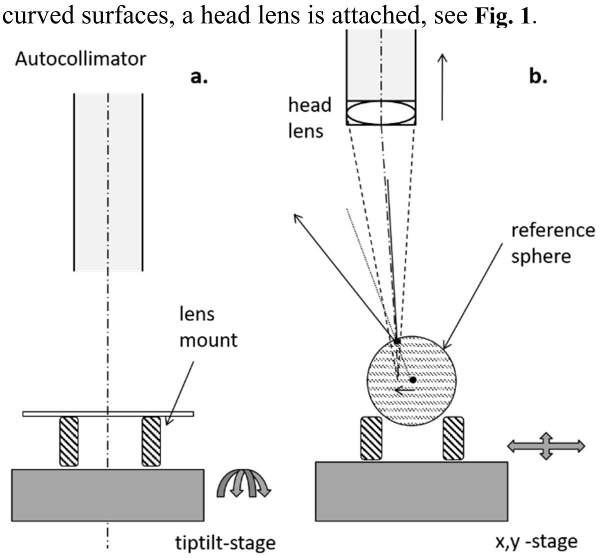

Fig. 1. Adjustment of the optical mount with respect to the autocollimator. Left: angle adjustment. Right: the centre of the reference sphere is adjusted to coincide with the focal point of the autocollimator head lens.

To measure different optical surfaces, the auto-collimator is translated along its axis (z). The focal point

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of the head lens thereby describes a line parallel to the autocollimator's translation axis. This line is the reference axis for the adjustment of the lens surfaces. When the head lens focal point and a centre of curvature lie in the same horizontal plane (x,y), the autocollimator measures the lateral distance between these points.

First, using reference mirrors and manual stages, the lens mount is adjusted in tilt (**Fig. 1**a) and translation (**Fig. 1**b), to reflect the autocollimator signal to the sensor's optical centre. Second, the lens is connected to a hexapod actuator and inserted into the mount. By lateral adjustment of the lens, the first centre of curvature C1 is moved to the reference axis (**Fig. 2**a). Then the hexapod's pivot point is placed (by software control) in C1. Tilting the lens about this point will not influence the first lens surface, while it allows the alignment of the second surface (**Fig. 2**b) until C2 and the reference axis overlap.

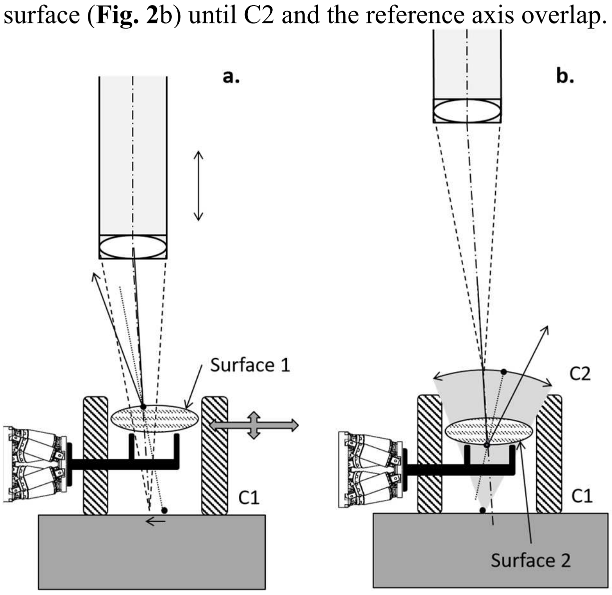

Fig. 2. Alignment of the lens with respect to the autocollimator. Left: lateral adjustment of the lens to move the first center of curvature C1 to the reference axis. Right: tilt of the lens to adjust surface 2, such that C1 is unchanged. Note that the mount position is not changed.

As a result of these process steps the mount front surface is orthogonal to the autocollimator's optical axis, and the lens optical axis is centred to the mount and parallel to the autocollimator's translation axis.

The process can be repeated for further lenses in the same mount. All lenses will be aligned to exactly the same reference axis. Since the centering errors are independent from mechanical interfaces of lens and mount, the mechanics can be kept relatively simple.

3 Test setup and results

Our alignment device contains an autocollimator AKG 300/40 (Möller-Wedel), a hexapod H-811 (PI), and a linear bearing LIMES 170 (OWIS), and is based on an existing alignment platform at Berliner Glas [3].

Two identical lenses (**Table 1**) were bonded in one mount, with 0.4mm adhesive gap. UV curing adhesive was used for lens fixation; an additional epoxy was applied for mechanical and temperature stability.

Table 1. Test system lens data.

Radius /mm	Index of refraction	Thickness /mm	Diameter /mm
R80.220	1.881	2.5	22
R39.625	1.497	4.6	22
inf	air	15	22
R80.220	1.881	2.5	22
R39.625	1.497	4.6	22
inf	air	-	22

Reproducibility measurements were conducted to characterize the setup, yielding <1µm measurement and alignment precision, and +-2µm stability of the reference axis over 500mm. Minor drift of the lens position was observed during UV curing and removal of the lens gripper. The largest error was caused by the cure of the additional epoxy.

The test assembly was measured independently on a centering measurement instrument OptiCentric (Trioptics) using the multilens software. The results of both measurements (**Table 2**) confirm that the displacement of the second lens centres of curvature with respect to the first lens optical axis is below 10µm. These results correspond to a tilt between the optical axes below 1 arcmin.

Table 2. Decentre measurement of the second lens with respect to the optical axis of the first lens.

		new alignment device	Opticentric
Surface decentre	1	6.1 µm	7.0 µm
Surface decentre	2	9.9 µm	3.5 µm
Tilt of the optical axis		0.3'	0.9'

The feasibility of high precision alignment by this new device is thus shown by two independent measurements. Further investigation of the measurement errors and improvement of the second adhesive bonding will establish the process limits. Based on the results for measurement and alignment reproducibility, we expect to reduce the centering error to 0.5 arcmin and 5 µm.

Rotation-free alignment bonding avoids the typical disadvantages of alignment turning, and can be considered a viable alternative for space sensitive products and rotationally non-symmetric optical systems.

Competing interests

Patent application 10 2020 107 298.8

References

1. P. Langehanenberg, J. Heinisch, C. Buß, C. Wilde *Optik&Photonik* (Wiley-VCH-Verlag, 2/2014)
2. Möller-Wedel Optical, *Beispiele zur Anwendung von Kollimatoren.* (Stand 18 März 2013)
3. S. Beyer, *Microalignment in der optischen Industrie* (tibb news 01/19)