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C. Wilde, P. Langehanenberg, T. Schenk, "Novel process for production of micro lenses with increased centering accuracy and imaging performance," Proc. SPIE 10448, Optifab 2017, 104480L (16 October 2017); doi: 10.1117/12.2279801

SPIE.

Event: SPIE Optifab, 2017, Rochester, New York, United States

Novel process for production of micro lenses with increased centering accuracy and imaging performance

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ABSTRACT

For modern production of micro lens systems, such as cementing of doublets or more lenses, precise centering of the lens edge is crucial. Blocking the lens temporarily on a centering arbor ensures that the centers of all optical lens surfaces coincide with the lens edge, while the arbor's axis serves as reference for both alignment and edging process.

This theoretical assumption of the traditional cementing technology is not applicable for high-end production. In reality cement wedges between the bottom lens surface and the arbor's ring knife edge may occur and even expensive arbors with single-micron precision suffer from reduced quality of the ring knife edge after multiple usages and cleaning cycles. Consequently, at least the position of the bottom lens surface is undefined and the optical axis does not coincide with the arbor's reference axis!

In order to overcome this basic problem in using centering arbors, we present a novel and efficient technique which can measure and align both surfaces of a lens with respect to the arbor axis with high accuracy and furthermore align additional lenses to the optical axis of the bottom lens. This is accomplished by aligning the lens without mechanical contact to the arbor. Thus the lens can be positioned in four degrees of freedom, while the centration errors of all lens surfaces are measured and considered. Additionally the arbor's reference axis is not assumed to be aligned to the rotation axis, but simultaneously measured with high precision.

Keywords: cementing on centering arbor, mandrel, micro lens doublets, cementing to optical axis, edge cutting, lens centering

1. INTRODUCTION

Micro lenses are increasingly used in a wide range of applications, such as fiber and laser optics, endoscopy, medical technology, detectors and many more. While special surrounding conditions require more compact dimensions of imaging systems, there is a great demand for increased imaging performance. In order to manufacture those small lens systems, the lens is usually blocked with temporary cement on a centering arbor (also known as mandrel) for handling, alignment, centering and edging. The shaft of the arbor serves as reference axis for required process steps on different machines. Thus, the initial placement of the lens on the arbor is crucial for the resulting imaging performance and strongly depends on the accuracy of this step.

The traditional cementing technology assumes that the ring knife edge of the arbor is perfectly coaxial with the shaft (see Figure 1). This assumption might be sufficient for low-cost applications, but for high-end production with the demand for single- or even submicron accuracy a deviation between the axes of shaft and ring knife edge is not acceptable. Due to mechanical tolerances of the arbor and especially deterioration of the knife edge quality with multiple usage and cleaning cycles, the required centration of the knife edge cannot be guaranteed. Since the bottom lens surface is considered to be in direct contact with the ring knife edge, the optical axis is not coaxial with the shaft of the arbor, even though the top lens surface might be aligned perfectly. Disregarding the centration accuracy of the knife edge and assuming a perfectly made arbor, another problem reduces the quality of lens alignment. If the lens is not in direct contact with the arbor, a cement wedge might displace the bottom lens surface from the center of the arbor, resulting in the same issue as described before.

In order to overcome the failing centration of the lens with respect to the arbor reference axis, either very cost intensive mechanical tolerances for the arbor have to be realized and retained, or a new strategy of active alignment needs to be applied, which is capable of measuring and aligning an optical axis with respect to a mechanical datum. The following graph (see Figure 2) shows in principle, that perfect alignment by targeting smallest mechanical tolerances might be less cost efficient than applying active optical alignment. The threshold of cost-efficiency certainly depends on the

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application. However, the cost of production increases disproportionately at least in the range of single-micron tolerance. Active alignment of the whole optical axis allows for highest alignment precision while using standard-precision arbors, since the constraint of mechanical contact between lens and arbor is omitted.

The content of the following chapters is proposing a new concept of active optical alignment. The process as well as the machine is introduced and described, which is capable of aligning a single lens or multiple lenses to a mechanical reference axis with highest possible alignment accuracy. In order to comprehend the novel measurement and alignment principle, the traditional processes are outlined first.

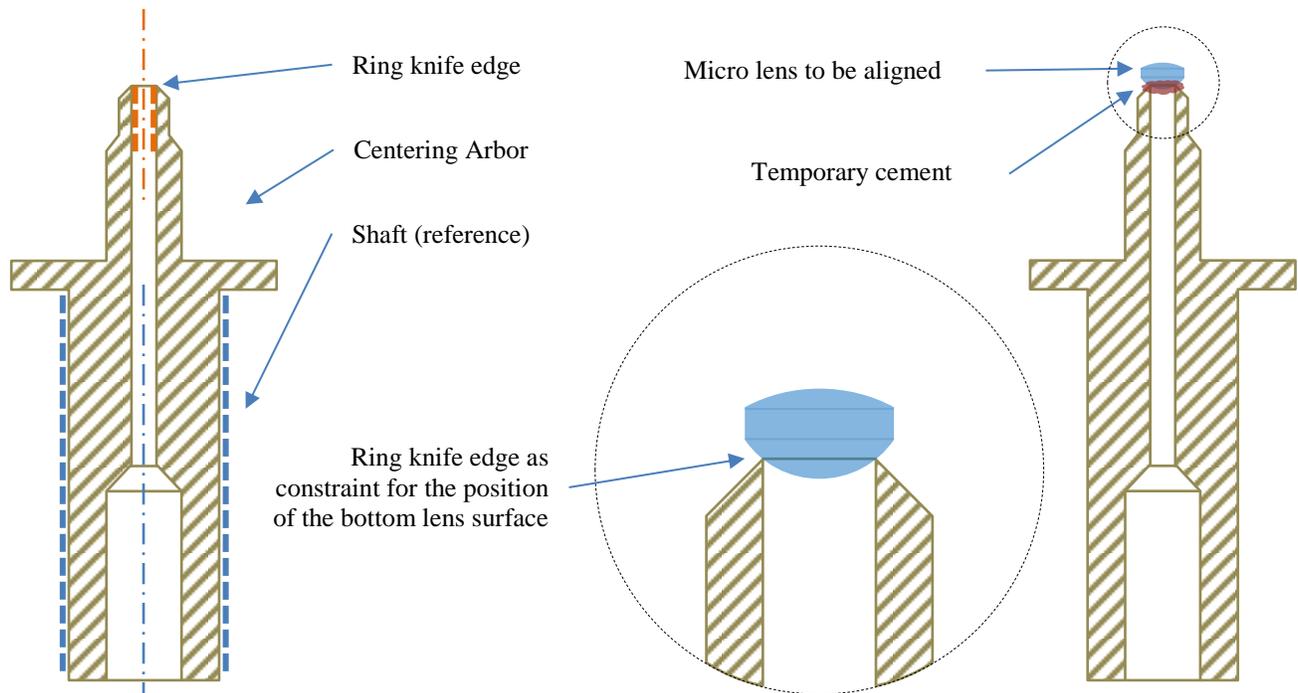


Figure 1. Drawing of a centering arbor without (left) and with (right) a cemented micro lens; constraint for the micro lens (center)

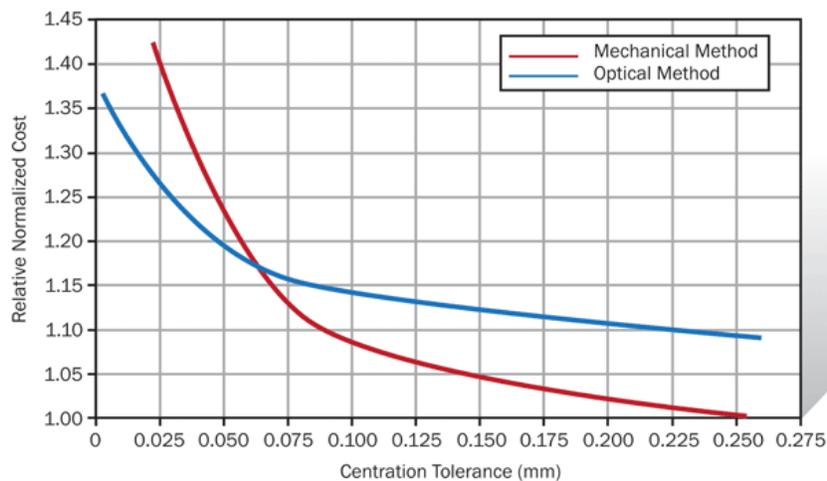


Figure 2. Relative normalized production costs for lens alignment with help of smaller mechanical tolerances vs. active optical alignment [1]

2. PRINCIPLES OF CENTERING ERROR MEASUREMENT

2.1 Centration error of optical surfaces

2.1.1 Measurement of a single surface

For measurement of the centration error of an optical surface, there are different methods established for production. The most common technique utilizes an autocollimator with laser beam or with a light source and reticle, which is imaged into the center of curvature of the top lens surface, as shown in Figure 3. 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, whose radius directly correlates with the centration error of the measured surface with respect to the axis of rotation.

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, spherical surfaces with short and long radii as well as for aspherical surfaces (on-axis measurement only).

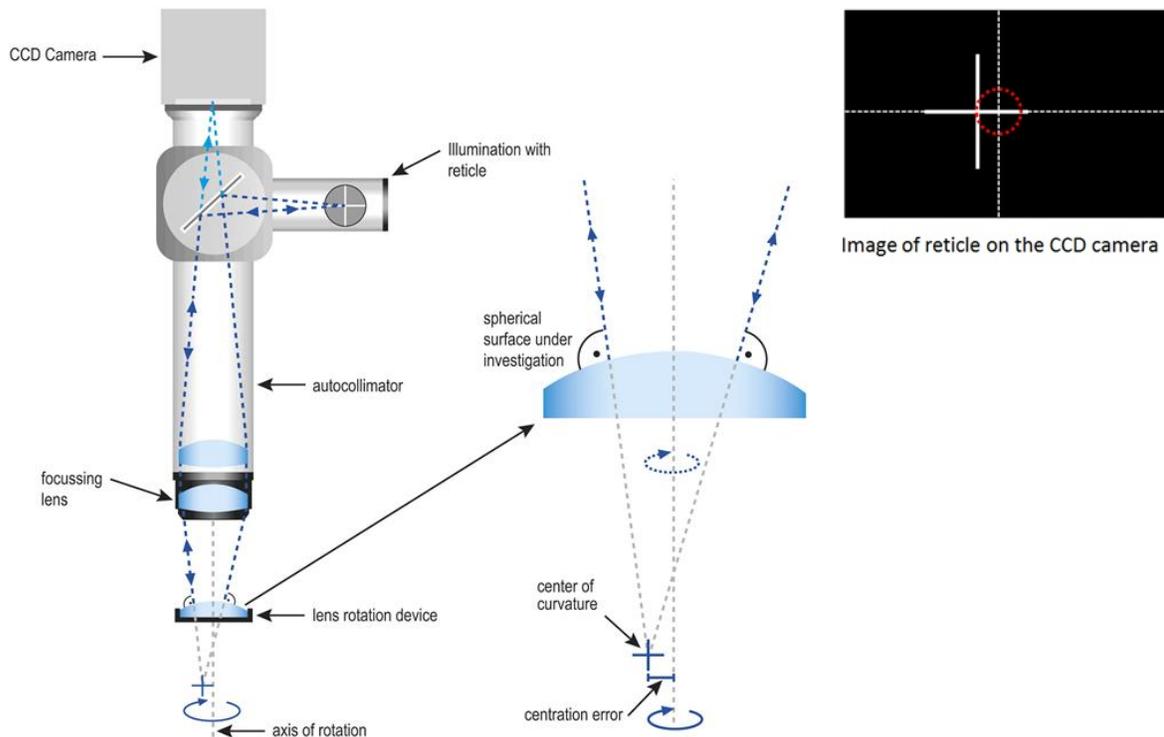


Figure 3. Measurement of the centration error in reflection mode with autocollimator and reticle

2.1.2 Measurement of multiple surfaces of a lens system

In order to measure the centration error of multiple surfaces of a lens system, additional efforts have to be made. The measurement described above has to be repeated for every lens surface, which requires a precise focus positioning stage. Furthermore the centration error as well as the diffracting properties of every lens surface above need to be considered by powerful software. By reason of measurement accuracy, the lens under test is placed on an air bearing with high precision runout and angular resolution, which is the reference for measurement.

This measurement procedure, also called MultiLens, is described more closely in [2]. An advanced measurement technique with simultaneous record of three surface positions is depicted in [3] and [4]. With help of the outlined MultiLens technology it is possible to measure the optical axis of a complete lens, as required for precise measurement and alignment of a micro lens to an arbor, described in chapter 4.

2.2 Centration error of a mechanical axis

For alignment of a lens to a mechanical axis, such as lens housing or centering arbor, it is important to determine the axis position as precisely as the optical axis of the lens. Mainly three different methods are established in production, which are expounded in the following chapters.

2.2.1 Mechanical axis as reference

The most common method for referencing a lens axis to a mechanical axis, e.g. arbor axis, is rotating the mechanical object around its cylinder axis. The arbor surface is pressed against a v-block and driven by a friction wheel (Figure 4). In this way the position of the arbor axis is not measured, but the axis acts directly as reference for the lens position measurement.

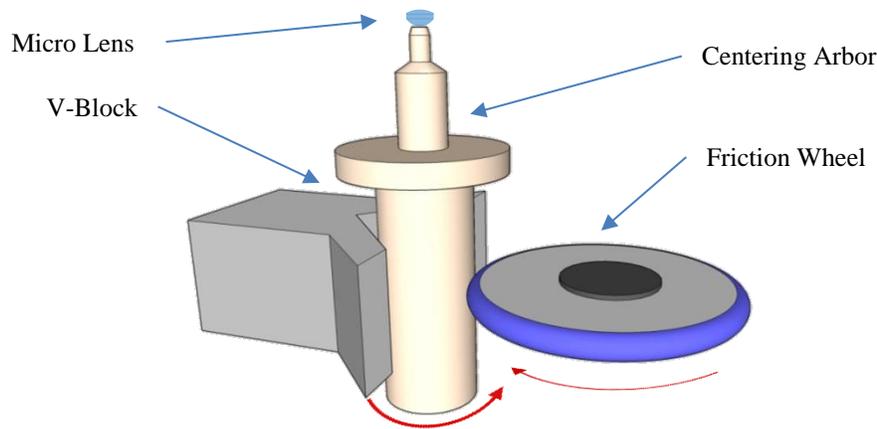


Figure 4. Referencing the top lens surface to the arbor axis by rotating the arbor in a v-prism

This technology is quite simple and very cost-efficient and thus widely used in production. But generally, it is only feasible for single lens surface measurement (reflection mode) and alignment. For high-end applications and particularly referencing of multiple lens surfaces to the arbor axis, a precise air bearing spindle is required. Moreover with this technique the lens cannot be held by a manipulator during measurement and automated alignment.

2.2.2 Air bearing as reference, mechanical axis pre-centered

If a highly precise air bearing is used as reference for measurement, the arbor can be fixed on a pre-centered high-precision (HP) collet chuck. In this case the position of the arbor axis is assumed to be identical with the rotation axis of the air bearing. Depending on the repeatability of the collet chuck, the remaining error between the arbor position and the air bearing axis might be insufficiently large and cannot be corrected.

This solution is more cost-intensive, but introduces new possibilities for measurement and alignment. Multiple surfaces can be referenced to an optical or mechanical axis and automated manipulators can be used, keeping the lens in position during measurement and alignment.

2.2.3 Air bearing as reference, mechanical axis measured

Considering the remaining centration error of the arbor axis allows for highest possible alignment accuracy. The axis position can be exactly determined with two precise distance sensors, which are measuring the cylinder surface of the arbor in a specified position. Applying this technique, as illustrated in Figure 5, the lens is not directly referenced to the arbor axis. Instead, after measurement of lens and arbor positions with respect to the rotation axis of the air bearing, the relative position between optical axis of the lens and mechanical axis of the arbor is computed by software. Using this powerful method, it is not required to use a HP collet chuck or to pre-align the arbor at all. By saving time of production and increasing measurement accuracy at the same moment, a new standard of technology is established.

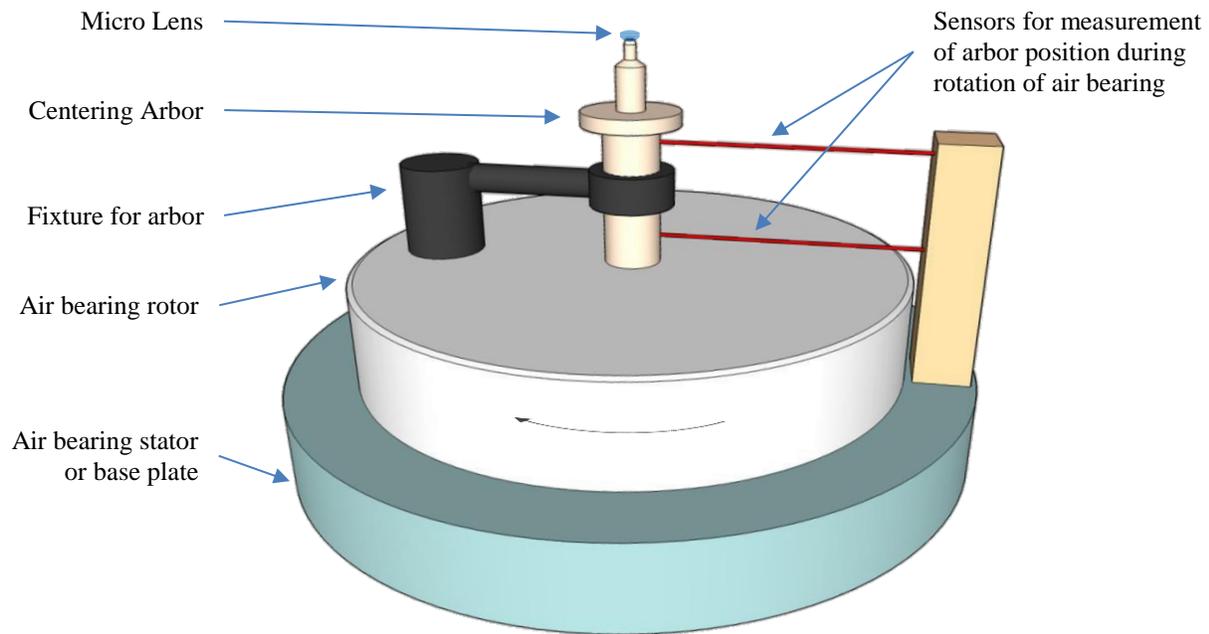


Figure 5. Measurement of the centration error of an arbor on an air bearing with distance sensors

3. PRINCIPLES OF LENS ALIGNMENT

The applied technology for alignment of a lens to a reference axis, e.g. centering arbor, strongly depends on the required alignment tolerance as well as the used measurement technology for the centration errors of lens and mechanical axis. A variety of methods for production exists, ranging from the simple bell clamping method without active alignment [5], over manual single surface alignment in two dimensions up to fully automated five-dimensional lens alignment [10].

The alignment processes described in the following chapters are based on the measurement techniques described in chapters 2.1.2 and 2.2.3 in order to achieve shortest possible production cycles with highest alignment accuracy. Alignment of a lens with respect to an optical or mechanical axis, which is just measured and not pre-aligned as described in chapter 2.2.3, is also termed as SmartAlign. A closer description of this technique can be found in [6] and [7].

3.1 Conventional Method: 2D-Alignment

Alignment of a lens to a mechanical axis in two dimensions is the standard of production worldwide. As the lens is directly placed on the mechanical reference, e.g. recess of a lens housing or ring knife edge of a centering arbor, the position of the center of curvature of the bottom lens surface is under constraint and cannot be aligned. However, the top lens surface is movable and can be aligned in two dimensions: depending on the lens design in tilt θ_x and θ_y (as with the illustrated sample in Figure 6) or in shift X and Y (as would be the case with a planar bottom surface).

After determination of the positions of mechanical axis and top lens surface, the lens' top surface is aligned with help of an actuator to the reference axis. The actuator can be a micrometer screw (manual alignment), an air pusher or an automated x/y aligner. Further applications and explanations about two-dimensional alignment are given in [8] and [9].

It is obvious, that the main limitation of this method is attributed to the mechanical tolerance of the ring knife edge, which determines the position of the bottom lens surface.

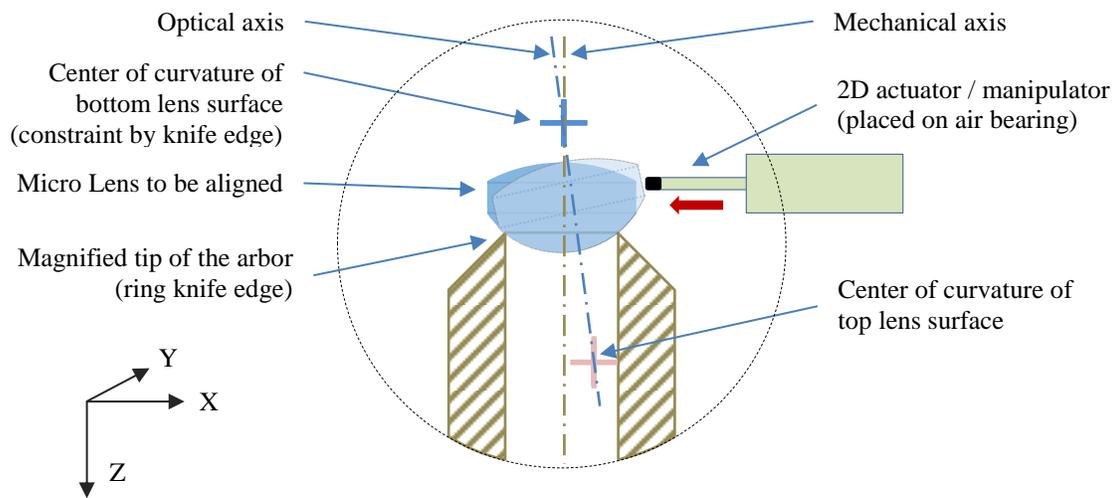


Figure 6. 2D-alignment of a biconvex lens to a mechanical axis (here: centering arbor) with an actuator; only tilt θ_x and tilt θ_y of the top lens surface can be aligned

3.2 Novel technique: 4D-Alignment

In order to overcome the constraint for the bottom lens surface, the lens needs more than two degrees of freedom for alignment. As illustrated in Figure 7, it is required to grip the lens and lift it slightly above the mechanical reference (tip of the arbor) with help of a micro gripper. This gripper is placed on an automated 4D-actuator, which is placed on the air bearing and is able to align the lens in tilt θ_x and tilt θ_y as well as shift X and shift Y. In this way both optical surfaces of the lens are actively aligned to the determined axis position of the arbor, using the life-feedback from the autocollimator (see chapter 2.1.1). The emerging gap between lens and arbor has to be filled with cement, which is cured after alignment.

An advanced description of the multi-dimensional alignment of a lens to a housing can be found in [10], describing a very similar technique, the so-called Bonding 5D.

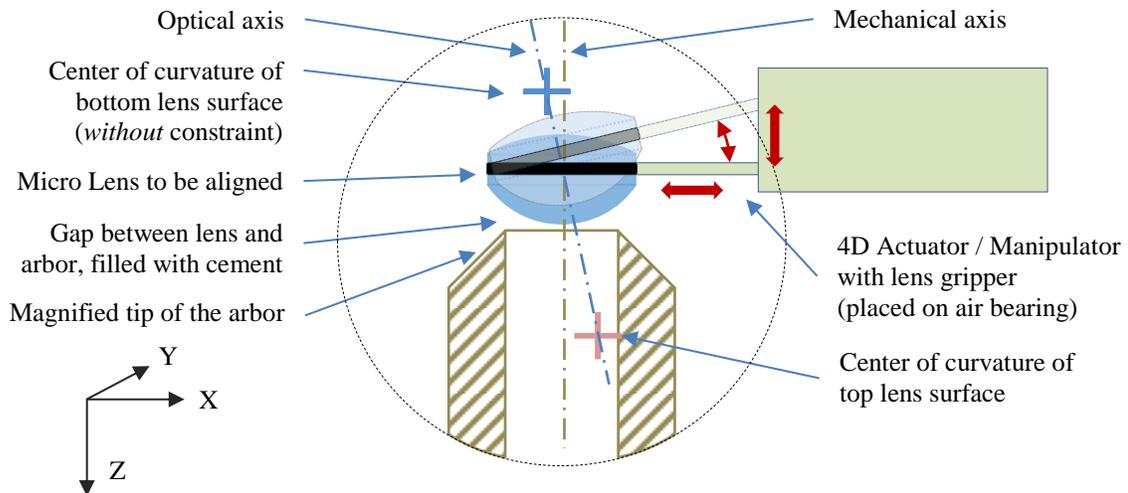


Figure 7. 4D-alignment of a lens to a mechanical axis (here: centering arbor) with an actuator; tilt θ_x and tilt θ_y as well as shift X and shift Y of the top lens surface can be aligned

4. PROCESS OF PRODUCTION

In order to understand the novel and very precise process of 4D lens alignment with respect to a centering arbor, the following section will give a short overview of the process steps.

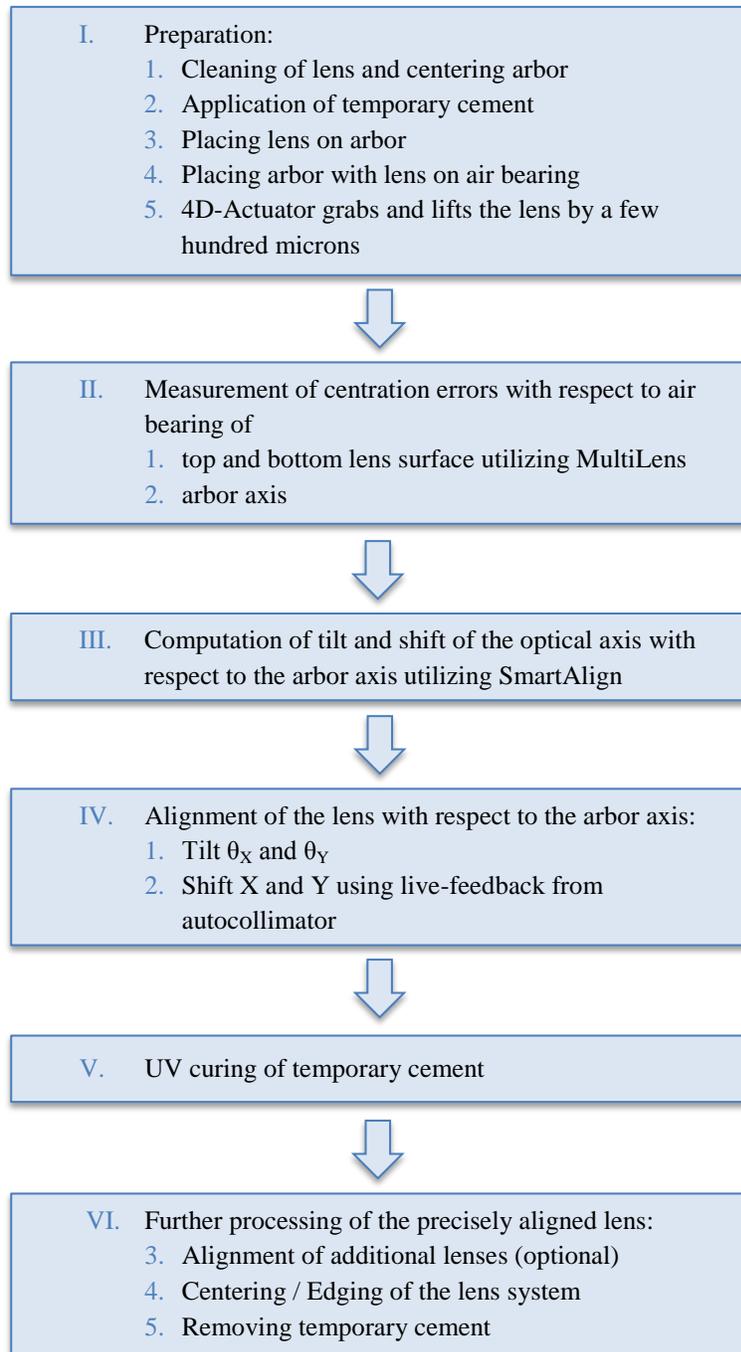


Figure 8. Process steps for production of micro lenses with increased centering accuracy and imaging performance

The novel process mainly differs from the traditional procedure in fixation, measurement and alignment of the lens and arbor. After cleaning of the components, the temporary UV cement is applied and the lens is placed on the arbor, floating on the cement. The arbor with lens is placed on a fixture on the air bearing and a micro gripper clutches the lens at its edge. In order to guarantee four degrees of freedom for alignment, the lens is lifted in z-direction by a few hundred microns, depending on the lens geometry. Subsequently the positions of the optical and mechanical axes are measured with respect to the air bearing, as described in the previous chapters. Once the positions are known, the software calculates the relative angle and shift between lens and arbor. The 4D-actuator first aligns the tilt of the lens and afterwards the shift of the lens by means of the autocollimator feedback. If the tolerance for alignment is reached, the lens is blocked on the arbor with help of UV light, which cures the cement within a few seconds. Now the lens is ready for further processing, such as centering or edging. Alternatively, additional lenses can be aligned and cemented on top of the first lens, building up a lens system.

5. DESCRIPTION OF THE ALIGNMENT DEVICE

The novel measurement technology outlined in the previous chapters is realized by TRIOPTICS GmbH with the production device OptiCentric® 100 and the module Lens Align 4D. The main components of the basic device are a highly precise air bearing with a runout of less than 50 nm and a high-resolution autocollimator with a CCD-camera (measurement accuracy of about 0.1 μm), which is placed on a motorized linear stage. The optional module “Lens Align 4D” consists of a pneumatic fixture for holding the arbor, a manipulator with micro gripper and high-precision piezoelectric 4D-actuators, and two distance sensors for measurement of the arbor’s axis position with a resolution of 0.1 μm. Except for the distance sensors, all parts of this module are placed on the air bearing, rotating with the sample 180 degrees. The interchangeable micro gripper holds the lens at the edge during the whole process and can be lifted by a stepper motor. With this device both centers of curvature of the lens can be aligned to the arbor’s axis with an accuracy of about 1 μm (shift) or 5 arcsec (lens tilt), respectively. The UV light from a LED light source can be coupled into the autocollimator, illuminating the sample from top, or optionally the LEDs can be fixed at the side. For convenient loading or unloading of the sample, the manipulator has an integrated lift. The cycle time for measurement, alignment and UV curing is about 1 minute.

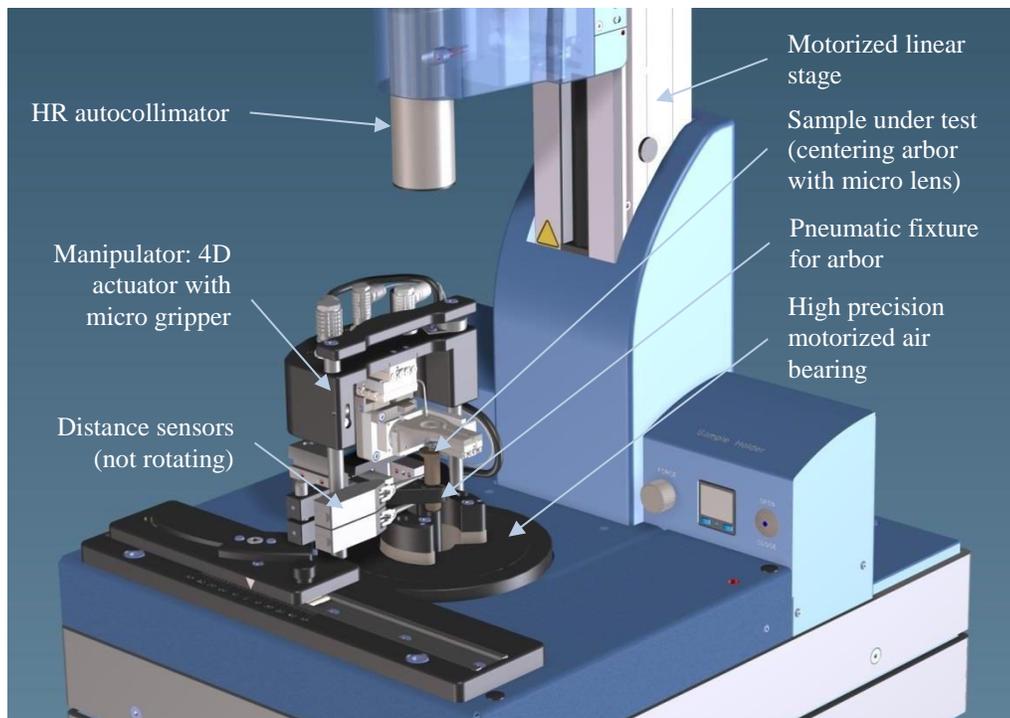


Figure 9. Setup of the device OptiCentric® Lens Align 4D (overview)

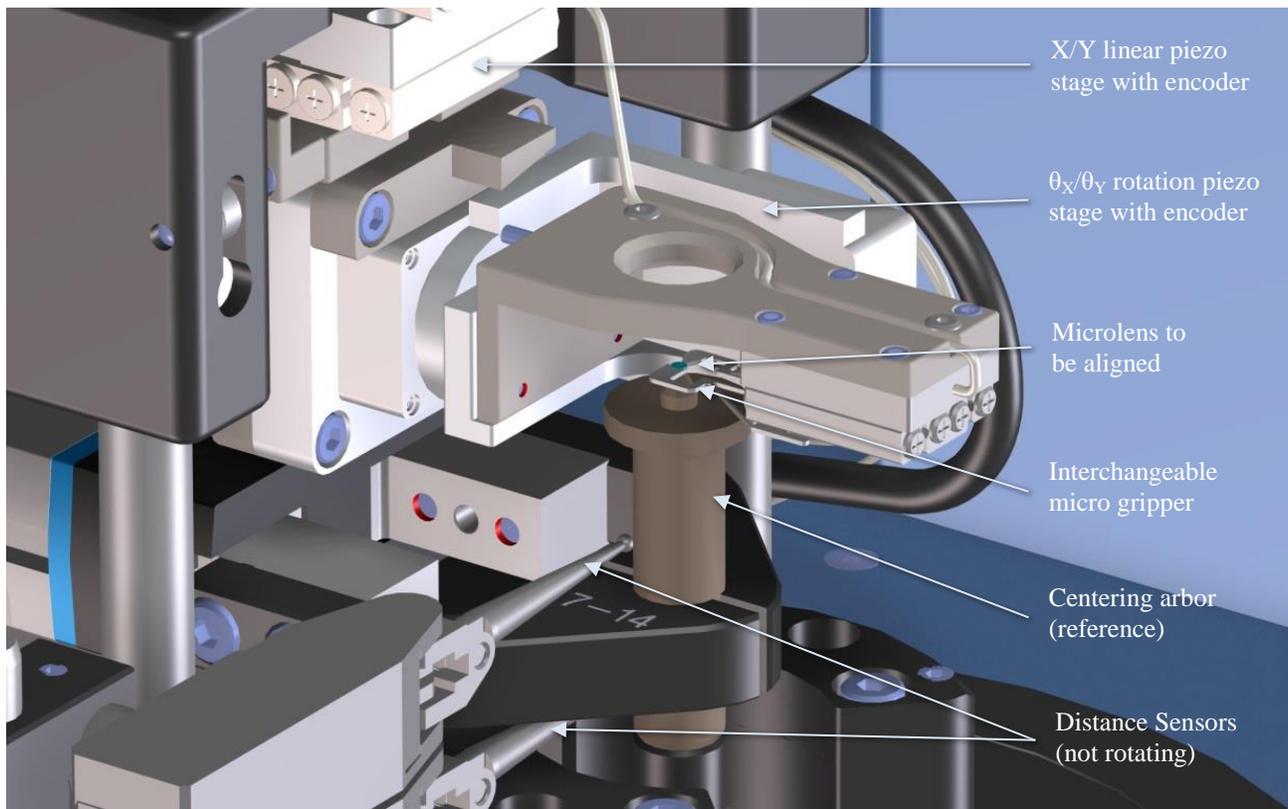


Figure 10. Setup of the device OptiCentric[®] 100 with Lens Align 4D (detailed view)

6. CONCLUSION

A novel metrology for production of micro lenses has been introduced, which has potential for increased centering accuracy of the lens and thus allows for better imaging performance of lens systems without the need for expensive mechanical tolerances. If the micro lens is aligned to the arbor's axis in the traditional way, only the top lens surface can be aligned with two degrees of freedom, because the ring knife edge of the arbor is a constraint for the bottom lens surface. With application of the novel technique, the lens is not in contact with the centering arbor and can be actively aligned in four dimensions, which makes it possible to align both centers of curvature to the mechanical reference. As a result, the influence of the ring knife edge can be neglected and centering arbors with standard accuracy can be used, because no cost-intensive tolerances for the edge are required. Furthermore the danger of a cement wedge is avoided, as the position of the bottom lens surface is not assumed to be on the arbor's axis, but measured and aligned precisely.

There are mainly three aspects, whose combination establishes a new standard of modern production: The technique for centration error measurement of multiple optical surfaces within a lens system (MultiLens), direct measurement of the centration error of a non-centered mechanical reference axis (SmartAlign) and 4D-alignment of the lens. By means of high-precision components, such as air bearing, autocollimator and actuator, an alignment accuracy of about 1 μm with respect to the arbor's shaft can be realized – for both lens surfaces and independent from the arbor's quality.

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