

# High-Precision Mounted Lens Production

## Directional adhesive bonding versus alignment turning

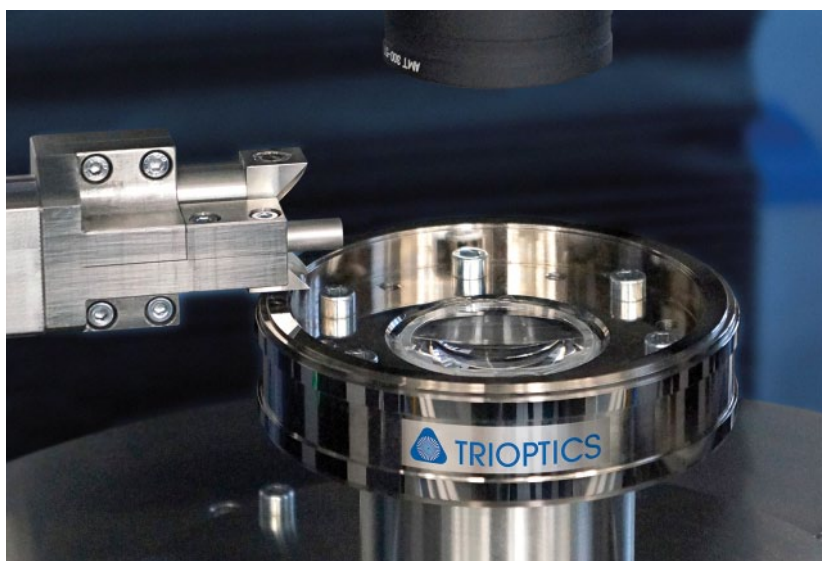
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Modern optic systems require modern assembly and joining techniques. The trend of keeping production dimensions as small as possible while maintaining or increasing optic imaging capacity leaves little room for mechanical equipment to align the individual elements in the end product. The two methods of directional adhesive bonding lenses in their final cell and alignment turning provide attractive solutions under these conditions.

### Measuring technology as a prerequisite for high-precision production

Measuring technology is inseparably linked to alignment and production technology, providing information about the geometric orientation of the lens to the mechanical cell. Both methods presented here use the same measuring technology to determine the position of the lens in the cell.

A high-precision reference axis (an axis of rotation in the processes described here) is a basic requirement for a high-precision measurement and production process. All measurements refer to this axis. In the directional adhesive



Mounted lens aligned, machined and tested with an alignment turning machine from Trioptics.

bonding procedure, the reference axis is the rotational axis of the air bearing spindle, which typically deviates from the ideal axis of rotation by a maximum of  $0.05\ \mu\text{m}$ . The spindles with direct-drive torque motors used in alignment turning are also able to achieve similar levels of precision.

Various measuring systems are used in order to precisely determine the position of the lens and cell. The results from

these measuring systems all refer to the reference axis.

The position of the lens is given by the position of the optical axis, which ideally is determined by means of two focused electronic autocollimators while the lens rotates  $360^\circ$  once around the reference axis. As a result, the shift of the center of curvature of the lens surface is determined with respect to the axis of rotation. The evaluation software then uses these data to calculate the spatial position of the optical axis (Fig. 1). [1]

The geometric position of the cell axis is determined using optical or tactile distance sensors. For example, the cell cylinder is detected in two z-positions while a test rotation of the sample records the runout. From the detected sine curve (Fig. 2), it is possible to calculate the decentration in the x and y components using the amplitude and phase. From this, the orientation of the cylinder axis can be determined while taking into account the measuring position in the z-direction. Referencing the mea-

## Company

### TRIOPTICS

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TRIOPTICS has been a leading manufacturer of optical measuring instruments for more than 20 years. With the broadest range of optical measuring instruments in the world, TRIOPTICS can advise its customer competently and independent of technology.

Today TRIOPTICS uses its measurement technology expertise in optics to develop high-precision manufacturing and automation solutions. The ATS 200 turning station is the company's latest development in this field.

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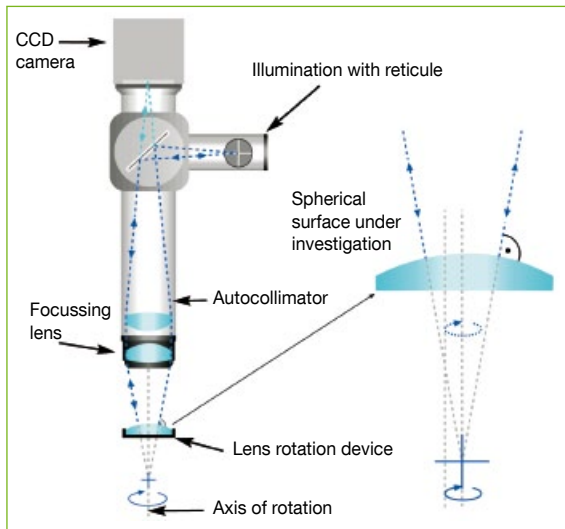


Fig. 1 Using an autocollimator to measure the center of curvature of a lens.

sured position of the optical axis to the orientation of the axis of the cell gives the centration error of the lens in the cell. [2]

An essential requirement for high-precision measurement and production is that all measurement data are measured and calculated with the aid of a computer.

Depending on the measuring method, the distance sensors allow an absolute measurement precision of less than  $0.5\ \mu\text{m}$ ; the autocollimators typically work with a precision of  $0.1\ \mu\text{m}$ .

### Strategies for aligning and bonding optics in a cell

In conventional alignment and bonding strategies for precision optics, all geometric elements (mechanical cell elements and optical surfaces) are ultimately aligned to one common reference axis. This alignment mechanism is complicated since positioning elements are required for all degrees of freedom. Furthermore, such procedures are time-intensive and production of the chucks commonly used is very expensive.

Trioptics is exploring new strategies, collectively known as *OptiCentric Bond-*

ing with “SmartAlign” Technology, with the goal of increasing production precision and repeatability while simultaneously reducing cycle times. This strategy puts into practice the concept of using an absolute minimum of alignment elements. The lens is aligned to an optical or mechanical target axis instead of referring everything to an additional auxiliary axis. It is not required that the target axis is centered in relation to the axis of rotation of the measuring system.

In the first step, the position of all relevant optical and mechanical components is determined. One  $360^\circ$  rotation about the reference axis is sufficient for this purpose, provided all sensors measure in parallel. In the second step the element to be aligned, e.g. a lens, is then specifically positioned on the previously defined target axis.

This SmartAlign strategy for alignment to a calculated target axis provides the foundation for the high-precision alignment of a lens to a cell axis. The strategy can be implemented in a number of ways, depending on the available or necessary degrees of freedom for alignment.

### Aligning a lens in a cell in two degrees of freedom

This process only allows for alignment in the x/y plane by means of lateral positioning of the lens element. In the example discussed in this case (Fig. 3), a biconvex lens is seated on a ring chuck within the cell. This means the position of the center of curvature of the supporting surface is fixed and determined solely by the precision with which the cell axis or ring chuck were manufactured. After applying UV adhesive between the lens and cell, SmartAlign will help to find the optimal position of the upper lens surface relative to the cell axis. A precision actuator is used

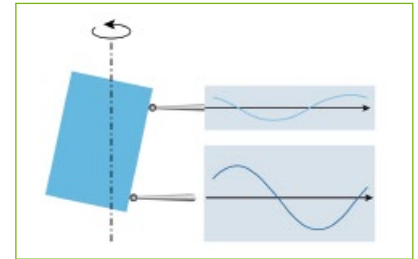


Fig. 2 The measuring sensors determine the shift and angle of inclination of the cell.

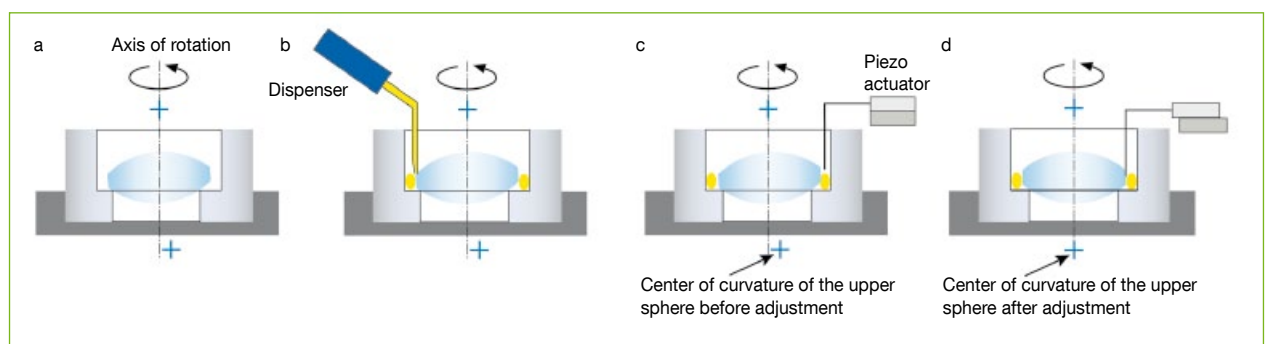
for the high-precision alignment of the lens surface. In the simplest case, a single actuator that aligns the lens at the corresponding azimuth position of the rotary table to the cell axis is sufficient. Depending on the mechanical accessibility and the throughput requirements, a system with three actuators, each offset by  $120^\circ$ , can also be used (see Fig. 5). Then the adhesive is cured with UV illumination and the lens, now precisely aligned to the cell axis, is fixed in place.

Should the production precision of the cell axis and ring chuck be inadequate for a satisfactory positioning of the lower surfaces, the procedure described above can be expanded, as shown in Fig. 4. In this two-stage process, the optical axis is first aligned parallel to the mechanical cell axis by tilting. Then the lens is bonded onto the support ring in this position. In the second stage, the parallel offset between the two axes is compensated for by shifting the lens support ring a defined distance. Using this two-step procedure enables the alignment of lenses with flat bottom surfaces.

The limitations of this procedure can be seen firstly in the eccentricity of the ring chuck and cell axis which are used to determine the centration error of the lower lens surface.

In this case, the free alignment of the lens within the cell described below is necessary.

Fig. 3 Alignment and bonding process in two degrees of freedom.



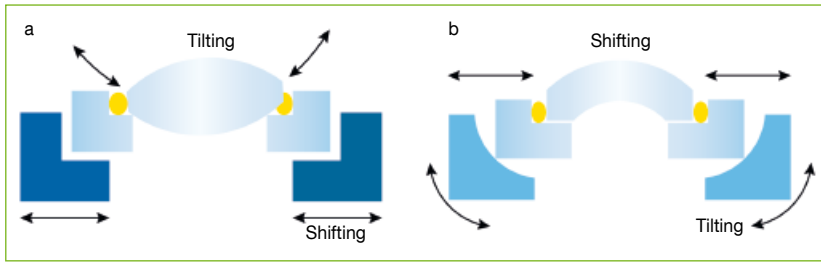


Fig. 4 Depending on the shape of the lens, the lens can only be tilted or shifted in its actual cell; the other degree of freedom is therefore aligned at a later point with the entire cell.



Fig. 5 Bonding station with three actuators for alignment in two degrees of freedom.

### Free alignment of a lens in five degrees of freedom

Aligning a lens in five degrees of freedom is designed to help further reduce centration errors by separating the process of aligning the upper and lower lens surfaces.

The lens is placed within the cell on a positioning holder such as an evacuated ring chuck or a three point support. In doing so the lens is not seated in the cell, but rather can be aligned on the positioning holder to any desired axis with five degrees of freedom, as shown in Fig. 6b) and 6c).

First UV adhesive is applied between the lens and cell. The reference axis for the measurement is also a high-precision axis of rotation. All necessary parameters are measured by the instruments with respect to this axis (Fig. 6a). In other words, two measurement sensors determine the cell's spatial position and autocollimators then determine the position of the optical axis of the lens.

With the help of the previously described SmartAlign technology, the lens in the positioning holder is then aligned so

that the optical axis of the lens is precisely aligned to the cell in tilt and shift (Fig. 6b).

Additionally this method can be used to determine the flange-vertex distance by means of a low-coherence interferometer. [3] To do this, a flat optic is placed on the flange, allowing the gap between the upper lens vertex and

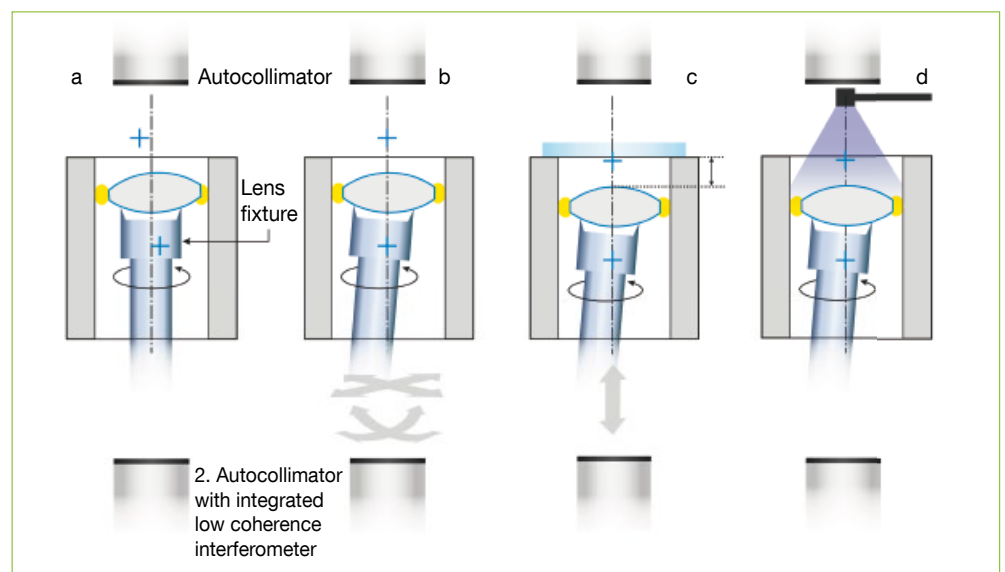


Fig. 6 a) The adhesive is applied to the edge of the lens and the spatial positions of the lens axis and cell axis are measured; b) The lens is aligned in the cell in four degrees of freedom; c) The axial gap between the apex point of the lens and a reference surface is measured and the lens adjusted axially; d) The adhesive is cured.

flange to be measured with a precision of  $<1 \mu\text{m}$  (Fig. 6c).

Depending on the type of adhesive used, it is hardened or cured by UV light (Fig. 6d).

The procedure is normally used to bond a single lens in a cell; the finished cell is then placed back in an objective lens. In principal, however, it is also possible to align and bond additional lenses to the same cell. Using this process the lens can be manually aligned in five degrees of freedom with a precision down to  $2 \mu\text{m}$ . With automated alignment – e.g. by using a hexapod – an alignment precision of approx.  $1 \mu\text{m}$  can be achieved, depending on production tolerances of the cell.

It is not just the mechanical positioning that limits the attainable precision: the fixing and bonding technique is critical, since for example shrinking during curing may affect the lens position. Last but not least, the precision of the cell also affects the measurement, aligning and bonding process.

### Alignment turning

In many cases the bonding process is undesirable or impossible due to a number of restrictions imposed by the application, the mechanical design of the lens cell or very tight tolerance requirements in terms of the lens assembly. A solution being developed by Trioptics is alignment turning with fully integrated measurement technology. Firstly, this process is



independent of the adhesive. Secondly, it is the only process capable of adjusting all relevant parameters of a mounted lens, in particular both vertex to flange distances. Furthermore, it can be used for a wider variety of cell sizes than the bonding process. Lastly, common precision lathes will allow for even tighter tolerances than other alignment strategies.

The process is described in the figures below. The lens cell, with an unaligned glued lens, is locked in place on an alignment chuck (Fig. 7). The alignment chuck is used to align the lens so that its center of curvatures coincide with the axis of rotation of the spindle. The spindle is then rapidly rotated and the surface of the cell is machined with a sharp (diamond) turning tool. The turning process provides a precise finish of the cell relative to the spindle axis. In addition to the outer surface of the cell, it is also possible to machine the front and rear flange surfaces.

In contrast to bonding, the lens is already fixed in its cell and this cell is then machined on the turning lathe with respect to the optical axis of the lens. This means that low tension adhesives with very long curing times can be used for high-precision optics. Also, the lenses may be crimped or held in place with clamping rings if the adhesive is not permitted for the planned application. Since the lens was aligned at the beginning of the process, the optical axis of the lens and the mechanical axis of the cell are precisely aligned with one another.

Alignment turning is the process that achieves the highest accuracy. Beside a granite basis and ultrastable axis, the alignment chuck and the integrated measurement technology play a key role:

The alignment chuck plays the most important role in achieving the maxi-

mum possible precision. A typical state-of-the-art system is designed as a plane-calotte chuck to separate the alignment of the tilt from that of the shift. It needs to have a high load capacity, be precisely balanced and not be disruptive while the process is running, e. g. through the introduction of heat near the area being machined. At the same time it needs to be both easily aligned and still have high grip strength so that even the smallest shift in position during machining is prevented. Using a vacuum chuck instead of mechanical or electrical solutions can be useful in meeting the last requirement. Compared to other means of clamping, the vacuum can be created outside of the machine to prevent any heat from entering the machining area. Applying compressed air during alignment allows for friction free shift and tilt movement, making this solution free of wear.

To achieve the required alignment accuracy, Trioptics uses high resolution autocollimators in its alignment turning stations. Further tactile and optional optical distance sensors are integrated into the machine, where optical sensors allow for the best accuracy. Using these sensors it is possible to establish an iterative machining process where the accuracy of the cell is checked after each step of machining. This gradual cutting of the cell ensures the highest achievable precision. Conveniently the cells used for alignment turning do not need to satisfy any extraordinarily tight tolerances before they are machined. They simply need to have sufficient dimensions which can then be machined off.

The distance between the lens vertex and the top flange surface of the finished lens cell can have a precision of up to  $0.5 \mu\text{m}$ . Its diameter can also be ma-

chined with an absolute precision of up to  $2 \mu\text{m}$ . The total remaining centration error can be reduced to less than  $0.5 \mu\text{m}$  through precise alignment. In addition, center thickness can be measured on the machine using a low-coherence interferometer. This makes it possible to machine both the top and bottom flange surface of the cell with the same high precision.

When assembling the lens, several mounted lenses machined in this way can be stacked into one lens barrel. This makes it easy to assemble mounted lenses without needing further alignment steps. Alignment is assured with micrometer accuracy thanks to the type of machining performed.

## Summary

The article describes the various procedures available for producing high-precision mounted lenses, based on the required precision.

The alignment turning method allows for the tightest possible tolerances. Due to the gradual machining of the mounted lens, the risk of not meeting the tight tolerances is minimal. It is also the only process that allows for precise corrections to all relevant degrees of freedom, e. g. the position of the lens with respect to the surfaces of the cell cannot be produced with the same level of precision using the other methods. Finally the alignment turning method may also be used for lenses which are not bonded in the cell but which are clamped in using some other means. Examples include lenses held in place with clamps or bolts. Thanks to this flexibility and precision, it is not only useful in serial production processes but also optimal for the production of smaller and medium-sized series.

However, the bonding process also has some advantages beyond the lower investment costs. Some of the technical benefits make the procedure interesting: you can easily use all possible materials for the cell, while the selection of materials for alignment turning may be limited by the turning machine. Furthermore, the bonding process does not depend on the geometry of the cell, while alignment turning can only be used for rotationally symmetrical cells and lenses.

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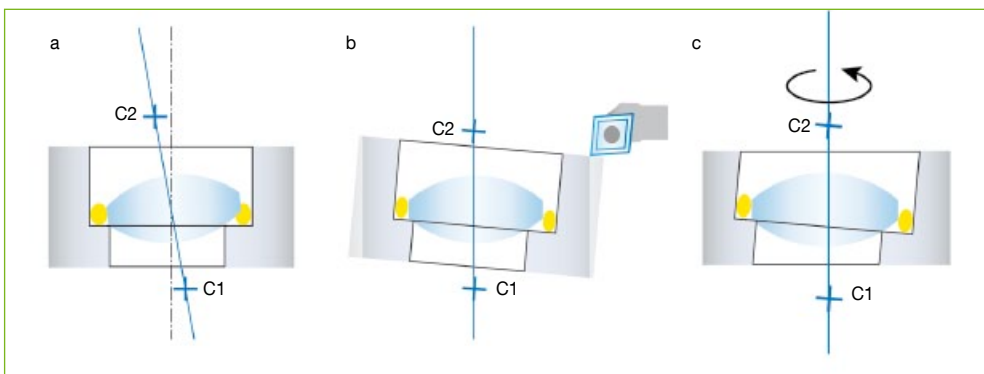


Fig. 7 Alignment turning process. a) Optical axis of the lens is determined, b) Cell is aligned to the optical axis of the lens, c) The edge of the cell is machined so that it coincides with the optical axis.

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