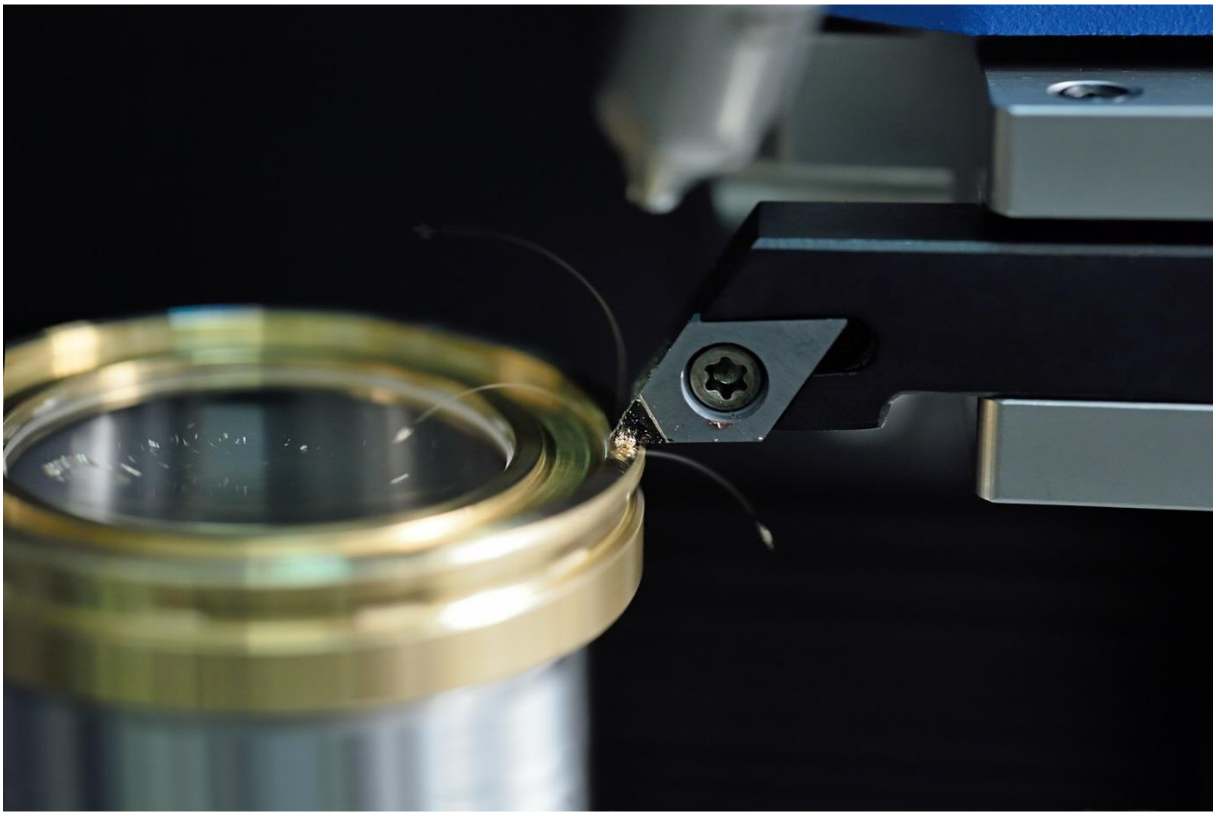
WHITEPAPER

High Precision Lens Assembly with Alignment Turning Machines

On Machine Metrology for the Alignment Turning Process



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Abstract

In recent years, alignment turning technology has experienced some key developments. Progress has been made with regard to aspheres, cylindrical surfaces or "best fit" centration of lens groups. It has also been possible to significantly increase the accuracy that can be achieved, in particular because the machines and control technology used have been optimized. Further accuracy gains for high precision optical assemblies are achieved when the processing and measurement sequences are optimized specifically for the sub-micron range. Iterative processing with integrated measurement of the reference surfaces is key to this.

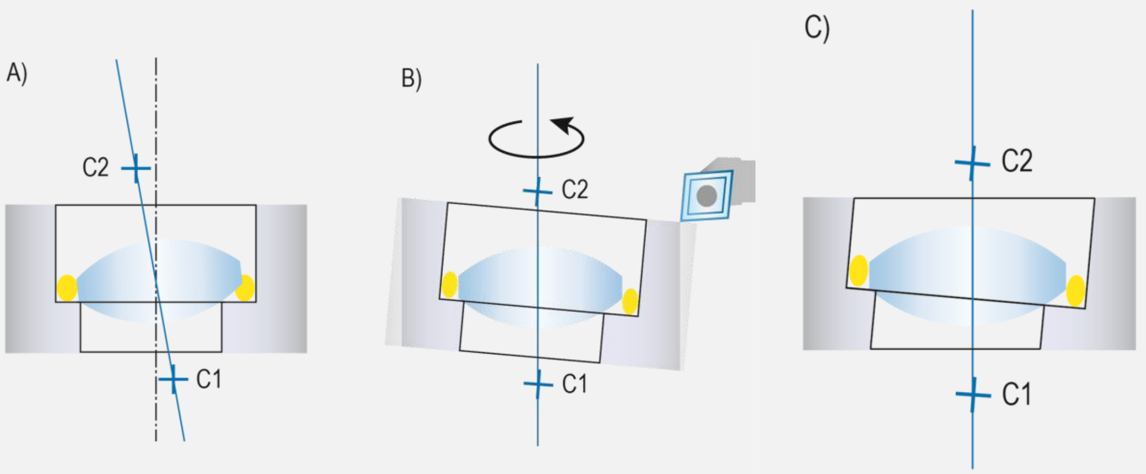
1. Introduction

The demand for optical assemblies with centration error and air gap tolerances at the scale of less than one micron is steadily rising. Traditional buyers for these high end products come from the semiconductor market, security and defense technology and from the aerospace industry. However, other branches of industry, such as medical technology, are increasingly demanding optical assemblies with the highest precision. In order to produce objectives and assemblies with such close tolerances, the alignment turning method is preferred. The centration accuracy of mounted lenses that can be achieved and the associated significant reduction in assembly costs of optical systems is one factor that supports alignment turning. Another is that it is the only alignment method – especially compared to alignment bonding – that allows specific adjustment of the air gaps through machining the axial reference surfaces. Furthermore, in an alignment turning process it is possible to machine optics completely independently of the properties of the cement or the lens fastening in the mount.

WHAT IS ALIGNMENT TURNING?

In the alignment turning process the optical axis of a mounted lens is aligned to the axis of symmetry of the cell. In doing so, the cell is machined so that the axis of symmetry of the cell and the optical axis of the lens coincide.

SCHEMATIC REPRESENTATION OF THE ALIGNMENT TURNING PROCESS



A) The optical axis of the lens is determined

B) The mount is aligned so that the optical axis of the lens corresponds to the spindle axis of the alignment turning machine. Then the reference surfaces of the mount are turned

C) The reference surfaces are now aligned to the optical axis

MORE INFORMATION ABOUT THE ALIGNMENT TURNING PROCESS:

http://www.trioptics.com/knowledge-base/alignment-turning-of-optical-assemblies/

The principles of alignment turning have been known for a while and frequently put to the test. Today, alignment turning machines are often based on in-house developments by companies that use the method for their own production. Often these are traditional (horizontal) turning machines that have been retrofitted with alignment chucks and optical or tactile centration measurement systems. These are primarily turning machines with alignment capability for optical elements.

Through diverse research and sponsorship projects, the alignment turning method has been scientifically studied and further developed. In addition, new applications for alignment turning have been opened up (for example machining mounted aspheres). Based on these developments therefore, the most stringent requirements are placed on machining accuracy, as listed in table 1.

Centration accuracy	
Lateral centration error (shift)	< 1 µm *(and better)*
Tilt	< 10 arcsec

Mount dimensional accuracy	
Cylindricity of the reference surfaces	< 0.5 µm
Planarity of the reference surfaces	< 0.5 µm

Accuracy of the reference surfaces	
Vertex gaps of axial references	< 1 µm
Diameter of radial references	< 2 µm

Table 1: Centration accuracy, production accuracy

In order to increase the accuracy of alignment turning machines even further, it is necessary to analyze what effect errors have on these close tolerances and specifically minimize them.

The centration accuracy that can be achieved depends to a large extent on the centration measurement technique used and the positional accuracy of the alignment chuck. Camera-based, electronic autocollimators have proven to be advantageous. These allow a direct assessment of the circle of radius of the individual spherical surfaces. Today it is possible to measure the centration error of a single surface with an accuracy of 0.1 µm. By using two electronic autocollimators, the centration error of a lens can reliably be measured with an accuracy of 0.2 µm or better. As an alternative to the second autocollimator, the patented MultiLens measurement method from TRIOPTICS can be used. Using a suitable alignment chuck, the remaining lateral centration error is adjusted to better than 0.2 - 0.3 µm. Accordingly, the available technology is suitable for measuring and adjusting the required centration accuracy.

WHAT IS MULTILENS?

MultiLens is a software feature from TRIOPTICS that is used to measure and align mounted lenses and objectives. The centration errors of each surface of a lens system and the centration of the overall system are measured non-destructively.

Using this information, it is possible to calculate and align the centration of a single lens or a sub-group to any freely selectable reference axis.

The cylindricity of the mount, the concentricity of the radial reference surfaces and the planarity of the plane reference surfaces mainly depend on the machining technology used. Available aerostatic and hydrostatic spindles have residual run-out errors of less than 0.1 µm and enable an achievable accuracy in the 0.1 µm regime. Provided the mounts are made from non-ferrous metals and diamond tools are used for alignment machining, the close dimensional tolerances of the reference surfaces are not an obstacle. In order to keep the effect of errors on the machine system as low as possible, following the design rules for ultra precision machines, all available machines are equipped with granite bases, vibration damping elements and high precision drive systems.

However, there are specific absolute parameters such as the diameter of the radial references and the vertex gaps of the upper and lower reference surfaces that determine the accuracy of the assembled objective. These parameters are directly associated with an individual mount, the specific machining process and the programmed machining sequences. This is explained if we consider that wear on conventional hard metal tools caused by turning is easily greater than the desired accuracy of the reference surfaces.

Measuring these parameters necessarily requires the integration of tactile and/or optical sensors in the machine control system. It is only in this way that machining can be undertaken specifically for each mount within the aforementioned tolerances.

2. Influences on Accuracy

The following influencing factors have to be taken into consideration in order to extract the best possible accuracy of a given alignment turning machine:

- Pairing of tool and material
- Process control / Machining sequence
- Sensors for dimensional measurement
- Measurement routine / Type of measurement

The most favorable pairing of tool to material is imparted individually by the optical and mechanical design of a mount and therefore does not have to be considered further. Therefore the following section discusses those possibilities to increase accuracy that can be obtained through optimized measurements and processes.

Process Control / Machining Sequences

Iterative machining sequences are used for highest precision optics. The target accuracy is not achieved in one or two machining steps with a deep cutting depth, but rather in several steps with a shallow cutting depth. Depending on the type of tool used, the cutting depth in these cases is then 50-100 µm for the coarse infeed and 10-30 µm for the fine infeed for finishing. Machining the final contour in two finishing cuts has proven to be particularly favorable. As a result, a check measurement can be performed before the very last infeed. If for example, a remaining material allowance of 20 µm is expected during this infeed but in actual fact 21.5 µm is measured, this

Tool wear has to be controlled before finishing cut may be due to wear on the tool. In this case it is possible to set the last finishing cut deeper by the measured difference in order to better achieve the specified dimension. With more accurate and more reliable measurement, any errors can be compensated, from wear on tools to errors that occur because tool and material have pushed away from each other during machining.

Sensors for Dimensional Measurement

All references that do not refer to a glass surface, especially inner and outer diameters are preferably measured with a tactile sensor. There is a wide range of different sensors that can be connected to the control system via different interfaces. It has been shown that sensors that have been developed for coordinate measuring machines achieve the best precision while simultaneously having low contact forces. If a suitable (short) sensor tip is chosen, the contact accuracy is around 0.5 µm and the repeat accuracy significantly less. Since it is always the same measurement that is performed, it is possible to achieve an absolute diameter accuracy of less than 2 µm by calibrating to suitable bodies. To this end, it is useful to perform the measurement so that it can be traced back directly to a reference that is as accurate as possible. If the alignment turning machine is equipped with linear scales from ZERODUR, it is possible to perform the length measurement in full with double-sided contact (see figure 1). The alternative of only sensing one side and tracing the value back to a previously determined reference involves a much larger error. Measuring both sides avoids thermal influences, because the measurement is done quickly. It also excludes the possibility that the reference itself is incorrectly positioned or is incorrectly measured.

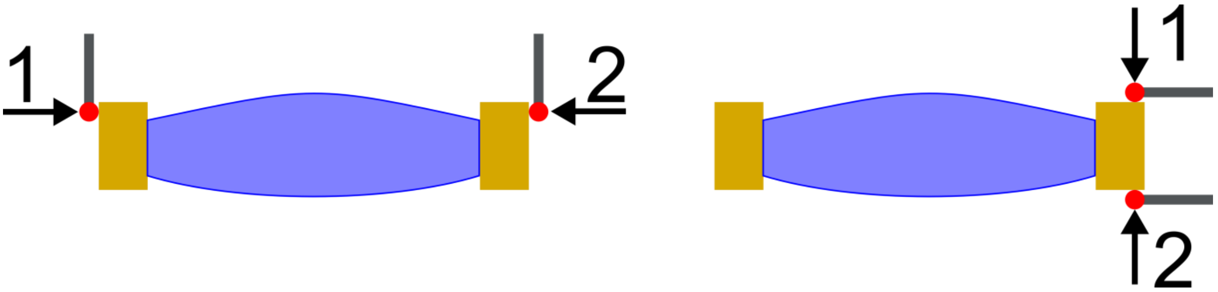
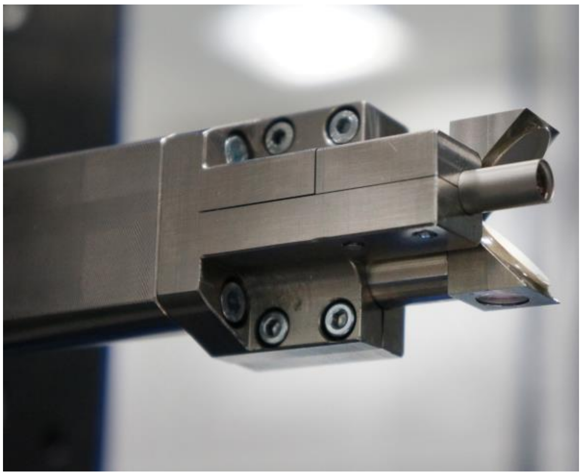


Figure 1: Double-sided contact measurement of references

For vertex gaps, optical distance sensors are particularly suitable where tactile contact measurement is not allowed. Chromatic confocal sensors have proven to be particularly expedient. Depending on the measurement head, these achieve an

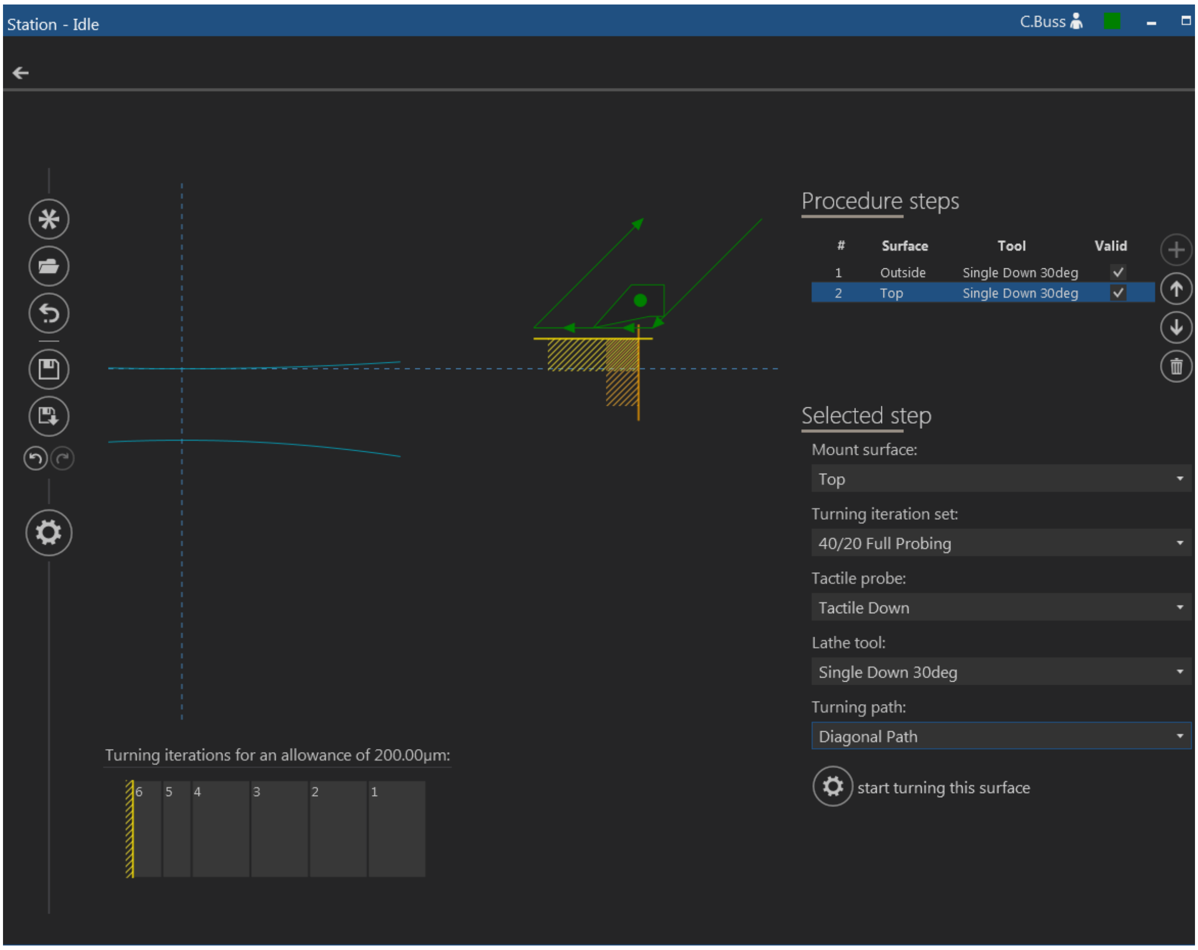

Sensor fort he measurement oft he outer cell diameter

accuracy better than 0.2 µm. In order to avoid linearity errors over the measurement range, it is wise to operate optical distance sensors as zero point sensors. In this way, the influence of the linearity error is avoided and the measurement can be traced back to a glass scale from ZERODUR in the same way as the tactile measurement. Thermal influences on measurement accuracy in particular are avoided.

In order to properly produce the vertex gaps of the lower surface, it is necessary to know the precise center thickness of the lens. This is preferably done directly on the machine, for example using a low-coherent interferometer. TRIOPTICS offers this type of measurement system under the OptiSurf® name with accuracies of up to 0.15 µm. The precise measurement of the center thickness requires that the measurement is done directly on the optical axis of the lens. Since the mounted lens is aligned to the spindle axis for the subsequent alignment machining anyway, the center thickness measurement is done on the alignment turning machine very precisely along the optical axis of the lens. Therefore in any case it is advantageous to perform the measurement on the alignment turning machine and not to resort to externally determined values.

Measurement Routines

Measurement routines ensure consistent production quality. Production reliability is achieved when measurement routines are software-based and automated. Figure 2 shows how such a software-based system may look. In the figure it can be seen how the software, based on information it has about tools and material, will perform the machining. The user can specify at what points of the process he wants to perform a check measurement. The machine software will warn the user on request if the measurement data deviate too far from the expected measurements. This avoids the possibility that the user, for example, has inserted the wrong mount into the machine or that an already machined mount is machined again.



Procedure steps

#	Surface	Tool	Valid
1	Outside	Single Down 30deg	✓
2	Top	Single Down 30deg	✓

Selected step

Mount surface: Top

Turning iteration set: 40/20 Full Probing

Tactile probe: Tactile Down

Lathe tool: Single Down 30deg

Turning path: Diagonal Path

Turning iterations for an allowance of 200.00µm:

Figure 2: Process sequence for alignment machining

Measurement routines have a large influence before the final machining step that occurs on the machine. It now has to be assumed that the mount has impurities, for example due to swarf. If an impurity is measured during the optimization measurement, the target accuracy can no longer be achieved. It is therefore advantageous not to perform the measurement at one point, but rather at several points. In this case the smallest measured distance can be used for optimization. Alternatively, the software can use the expected value in order to only repeat the measurement in cases where the measurement exceeds a specified upper limit for the deviation to be corrected (for example 5 µm). This is useful firstly because frequently only one measurement is necessary and the cycle time is not extended, and secondly only those values that can actually be attributed to wear on tools or similar effects are corrected.

3. Summary

TRIOPTICS ATS 200

The integration of (dimensional) measurement technology, i.e. optical and/or tactile sensors in an alignment turning machine, is a necessary prerequisite in order to satisfy the accuracy requirements of high precision optical assemblies. However, this precision can only be made usable by its intelligent integration into the control software. Determining factors such as wear on tools or process-specific properties of the mount material can be specifically minimized through iterative processing.

It can be seen that the user of such a machine is presented with a graphically formatted view of the process. Therefore the user does not have to intervene directly in the machine program. However, if this is desired, the option is of course there. The software can also be connected to production databases and enables the retention of all results without interruption up to the final assembly of an objective. Thanks to the integrated centration measurement technology, it is possible to measure an objective in its entirety on the machine even after the objective has been assembled, without needing an additional device. Small and medium sized businesses in particular benefit from smart software and can expand previously available measurement systems or even replace them completely.

Moreover, if it is possible to design the machine to be so simple and user-friendly to operate, without the user having to program individual steps, small and medium sized businesses can now enter the field of alignment turning without in-depth knowledge of machining technology.

More Information:

- Live demo of TRIOPTICS ATS 200 at SPIE OptiFab 2015, booth 115
- ATS 200: http://www.trioptics.com/products/alignment-turning/ats-200/