ATS 200 & ATS 400
Alignment Turning Stations with Fully Integrated Measurement Technology
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATS - Alignment Turning Station</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>The Principle behind Alignment Turning</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Typical Applications for Alignment Turning Stations</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>ATS 200</strong></td>
<td>8</td>
</tr>
<tr>
<td>Vertical Design with Granite Base</td>
<td>9</td>
</tr>
<tr>
<td>Aerostatic Bearing Axes</td>
<td>9</td>
</tr>
<tr>
<td>Alignment Chuck</td>
<td>10</td>
</tr>
<tr>
<td>Integrated OptiCentric® Measuring Technology</td>
<td>11</td>
</tr>
<tr>
<td>Additional Measurement Technology</td>
<td>12</td>
</tr>
<tr>
<td><strong>ATS 200 Software</strong></td>
<td>13</td>
</tr>
<tr>
<td><strong>Upgrades and Accessories</strong></td>
<td>14</td>
</tr>
<tr>
<td>&quot;Larger Workpiece Size&quot; Upgrade</td>
<td>14</td>
</tr>
<tr>
<td>&quot;Second Autocollimator&quot; Upgrade</td>
<td>14</td>
</tr>
<tr>
<td>&quot;Production of Aspherical Lenses&quot; Upgrade</td>
<td>14</td>
</tr>
<tr>
<td>Four-Way Tool Changer</td>
<td>14</td>
</tr>
<tr>
<td>Optical Distance Sensor</td>
<td>15</td>
</tr>
<tr>
<td>Automated Head Lens Exchange</td>
<td>15</td>
</tr>
<tr>
<td>Set for Regular Calibration</td>
<td>15</td>
</tr>
<tr>
<td><strong>ATS 400</strong></td>
<td>16</td>
</tr>
<tr>
<td>Main Advantages of the ATS 400</td>
<td>16</td>
</tr>
<tr>
<td>The ATS 400 Software</td>
<td>17</td>
</tr>
<tr>
<td><strong>Technical Data for ATS 200 and ATS 400</strong></td>
<td>18</td>
</tr>
</tbody>
</table>
ATS – Alignment Turning Station

Alignment Turning Station with Fully Integrated Measurement Technology for High-Precision Manufacturing of Mounted Lenses

Increasing demands on optics precision require a close connection between manufacturing and measuring technology. Alignment turning is the future for high-precision manufacturing of mounted lenses.

TRIOPTICS specializes in optical measurement technology and with its OptiCentric® centration measurement system it is a world leader. TRIOPTICS has incorporated this system into alignment turning stations from different manufacturers, recognizing the benefits that an alignment turning station with fully integrated measurement technology would offer: improved process control, simpler operation and high flexibility in the integration of additional measurement technology.

In order to offer these benefits to its customers, TRIOPTICS has expanded its product portfolio with alignment turning stations and is marketing this new product group as "ATS – Alignment Turning Station".

The ATS 400 was the first step in this new direction. It was developed in cooperation with LT Ultra and is preferably used in the production of stepper lenses.

ATS 200: The Alignment Turning Station with the Widest Range of Applications in its Class

Now the ATS 200 is being presented as the first self-developed product in this range, which has the widest range of applications in the class for mounted lenses up to 200 mm diameter: spherical, aspherical and infrared lenses can be measured with an accuracy of 0.25 \( \mu \text{m} \) thanks to TRIOPTICS measurement technology and their cells manufactured with an accuracy of 1 \( \mu \text{m} \). The maximum sample weight is 5 kg. Hence the ATS 200 is always the right choice when the widest variety of orders for a prototype and medium-sized production run need to be met with the highest precision.

In addition to the OptiCentric® centration measurement equipment, the ATS 200 is equipped with tactile or optical sensors to measure the front and rear contact surfaces of the mounted lens in a series production environment. Optionally, additional measurement equipment from TRIOPTICS can also be incorporated, such as the OptiSurf® center thickness measuring system.

An intuitive and intelligent user interface guides the operator through the alignment turning process. On the one hand it is measuring software for the autocollimators and

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.
distance sensors while also controlling the alignment chuck. And on the other hand it is also operating software for the turning machine and has tool management features and corresponding setup and calibration routines.

When designing the alignment turning station, TRIOPTICS worked closely with renowned manufacturers of turning machine components and placed the highest emphasis on quality in all components, resulting in a granite platform with three ultra-high precision aerostatic bearing axes, integrated vibration isolation and the consistent exclusion of interfering sources of heat in the working area. This all comes together to create a system with the highest precision and a wide range of applications.

Alignment turning is the only method by which all relevant parameters of a mounted lens can be aligned, in particular the gap between two apex points and the contact surface. In addition, a large number of different cell sizes can be processed. And finally, high precision turning machines achieve excellent production accuracies of up to 0.5 μm.

The alignment turning method is described in the figures below (Fig. 3). In alignment turning, first the lens cell is fixed in an adjustable alignment chuck with the lens in place. Then the position of the optical axis of the lens to the spindle axis is measured with the OptiCentric® system. Using this alignment chuck, the lens is then aligned so that its two centers of curvature are located as closely as possible to the axis of rotation of the spindle.

Fig. 1: The optical axes do not coincide with the axis of the barrel; lens distances are not correct
Then the spindle is rotated and the contact surfaces of the cell are machined with a sharp (diamond) turning tool, resulting in a precisely machined surface of the cell, aligned parallel to the spindle axis. In addition to the outer surface of the cell, it is also possible to machine the front and rear contact surface during the turning process. To do this the turning tool is moved perpendicular to the spindle axis instead of along the optical axis.

The lens is already fixed in the cell during the alignment turning process. This means that low-stress adhesives with very long curing times can be used for highly precise optics. Similarly, the lenses can be crimped or held by screw rings when the available adhesives are not suitable for the intended application. Since the lens has been aligned at the beginning of the process, the optical axis of the lens and the mechanical axis of the cell are aligned parallel.

Fig. 3: The alignment turning process A) optical axis of the lens is determined, B) & C) cell is aligned to the optical axis of the lens, the edge of the cell is machined so that it is parallel to the optical axis.
The Principle behind Alignment Turning

precisely aligned when the cell is machined on a turning machine corresponding to the optical axis of the lens.

In order to achieve high accuracy TRIOPTICS has integrated additional measurement technology into its alignment turning stations, alongside the high-resolution autocollimators. These include tactile and optical distance sensors that ensure a highly accurate measurement of the relevant mechanical parameters. This means the highest precision is achieved by a gradual machining process, in which the cell accuracy is checked after each machining step. The cells used in alignment turning do not need to meet exceptionally tight tolerances before machining. The cell offset only needs to be large enough to meet the required tolerance after machining.

The distance from the lens vertex to the upper contact surface can be manufactured with an accuracy of up to ±0.5 µm. Similarly, the diameter can be manufactured with an absolute accuracy of ±2 µm. The remaining centration error can be reduced to less than 0.5 µm by using a suitable alignment chuck. Moreover, a low coherent interferometer can be used to measure the center thickness on the machine, so that the contact surfaces can be manufactured with high precision with respect to each lens vertex. Multiple mounted lenses manufactured by alignment turning are then assembled to an objective lens. The method of machining in the micron range ensures that all lenses are aligned to each other. This allows mounted lenses to be assembled in a tube without further adjustment steps.

More Information about Centration Measurement
OptiCentric® products are world leaders in centration measurement. For more information about centration measurement of various optics, please refer to our OptiCentric® product brochure. Special features and detailed application examples for measuring infrared lenses can be found in our application brochure.

More Information about Low Coherent Interferometers
OptiSurf® is TRIOPTICS’ low coherent interferometer and measures center thicknesses with an accuracy of up to 0.15 µm. For more information about TRIOPTICS’ low coherent interferometer please refer to our OptiSurf product brochure.
The alignment turning procedure has a very broad range of applications, from the smallest lenses used in microscope objectives through to lenses for i-line steppers. The ATS 200 and ATS 400 alignment turning stations allow the manufacturing of almost all types of mounted lenses:

- Lenses for stepper objectives
- Lenses for microscope objectives and endoscope optics
- Mounted infrared lenses for safety applications
- Machining mounted aspherical lenses
- Lenses and components for high-quality digital camera objectives
- Lenses which cannot be glued in cell, e.g. for space applications
- Imaging optics for UV applications
- Optical assemblies with very high accuracy requirements
ATS 200

Manufacturing Mounted Spherical, Aspherical and Infrared Lenses with up to 200 mm Diameter

The ATS 200 was developed with the aim of simplifying the alignment turning of mounted lenses for the user. TRIOPTICS has extensive experience and patented technology for measuring the centration of lenses and objectives. Moreover, TRIOPTICS has been using high-precision air bearing spindles and linear stages for many years. The development of a proprietary alignment turning machine is therefore a logical step for the advancement of its technology.

Modular Design

The ATS 200 uses a modular design, which is particularly advantageous for medium batch sizes since the machine can very easily be set up for new cell types and sizes.

The basic configuration provides a fully functional alignment turning station. Add-ons make it possible to respond flexibly to increasing demands: change in the diameter range, production of aspheres or infrared lenses, integration of additional measurement technology.

Intuitive Operation

Particular emphasis was placed on developing the operational concept. Joining machine control and measurement software makes it easier for the operator to produce mounted lenses with maximum accuracy. In-depth knowledge about conventional machine programming is not necessary.
Vertical Design with Granite Base

All stages and the machine base are made of fine porous natural granite. The compact design, optimized for stability, increases the rigidity in the machining zone and makes the ATS 200 resistant to external influences such as changes in temperature. Vibration damping of the granite base ensures insensitivity to vibrations.

The vertical design of the ATS 200 was chosen for three reasons: Firstly it prevents the spindle causing a tilting moment during machining, which could reduce accuracy. Secondly, the footprint of the machine is reduced. Finally, the vertical structure design is an elegant solution for convenient loading and unloading of the machine, which is particularly relevant for heavier samples.

Aerostatic Bearing Axes

The ATS 200 is equipped with precision air bearing linear axes and an air bearing main spindle with large through bore. Aerostatic axes are fully wear-free and only need to be serviced on an extremely small scale. They also guarantee that the axes move with high accuracy and extremely smoothly. This is important because it allows the highest accuracies to be achieved at the submicron scale. The extremely compact design of the axes is the result of the structure-related finite element analysis.

Both the main spindle and the two linear axes for machining are driven by brushless DC motors. Each of these axes has glass measuring scales of the highest accuracy class. The CNC controller used for this purpose has been selected so that process accuracies in the range of 0.1 µm can be achieved. Consequently, the machine is able to comply with even the smallest of tolerances on the finished surfaces.
**Alignment Chuck**

The alignment chuck is a crucial element in achieving high accuracy during machining. It aligns the optical axis with respect to the rotational axis of the spindle. TRIOPTICS has been producing this type of alignment chuck for some years now and right from the start of development placed the highest value on compatibility for precision machining.

Alignment turning using an alignment chuck is a very simple and intuitive process. Centration errors are displayed during the entire alignment procedure. This provides the operator with reliable feedback about the alignment accuracy that is being achieved.

The alignment chuck on the ATS 200 is designed as a plan/calotte chuck in order to be able to adjust the tilt as far as possible without affecting alignment of the shift. It has a very high load capacity and is suitable for a wide range of cell diameters. At the same time, it can easily be adjusted and yet still has a high clamping force to rule out even the slightest changes in position during machining. This is achieved by the fact that the chuck uses a vacuum instead of a mechanical or electrical clamping method. In contrast to other clamping methods the vacuum can be generated outside of the machine, thus preventing the heat from entering the machining space. In order to attain additional reliability, a preload is integrated on the basis of permanent magnets. Compressed air is applied during alignment to adjust the tilt and shift without friction and thus without wear to the parts.

In addition to spherical lenses, the alignment chuck used on the ATS 200 is also suitable for holding optical elements that do not have a conventionally defined optical axis through two centers of curvature. This includes prismatic optical elements in addition to aspherical lenses.

**Manual Alignment Chuck**

The manual alignment chuck is operated with four adjusting screws, one for each of the four degrees of freedom. It is designed as a plan/calotte chuck and is suitable for all spherical and aspherical lenses. The manual operation means other optical components, such as prisms, can easily be adjusted.

**Automated Alignment Chuck**

The automated alignment chuck is intended for applications where the speed of the alignment process is important, for example in series production. The automated alignment also largely rules out operator error. As with the manual chuck, first the centration error is determined. The software then calculates the necessary alignment needed to correct the
Tilt and shift of the lens. Finally, the alignment chuck is adjusted to the calculated position. The automated alignment chuck is also suitable for heavy lenses thanks to its load capacity. In order to optimize the positioning speed, the motors should be attuned to the lens weight for the highest accuracy. The target accuracy to be achieved and the necessary positioning parameters can be configured in the software.

**Integrated OptiCentric® Measuring Technology**

The ATS 200 is equipped with a centration measurement system from the OptiCentric® range. The autocollimator used here with a 300 mm effective focal length measures the centration error of a lens with an absolute accuracy of 0.25 µm.

The ATS 200 is equipped with one centration measurement head as standard. Thanks to the MultiLens technology developed by TRI-OPTICS, centration errors of both lens surfaces in a cell can be determined with just one autocollimator. In addition, the ATS 200 can be fitted with a second measurement head that is directed to the mounted lenses from below. Firstly, this allows a more rapid measurement of both lens surfaces. Secondly, it means that centration errors of non-transparent optics can be measured, such as germanium lenses for the infrared light spectrum.

The autocollimation heads are mechanically stably connected to the machine granite. Linear axes with ball bearing spindles ensure high repeatability of positioning. The measurement resolution of less than 0.2 arcsec is achieved by an autocollimator with a 300 mm effective focal length. This is equipped with a high resolution CCD camera connected to the control computer for automatic evaluation. High-power LEDs provide the necessary light, even when working with optics with anti-reflection coatings.
Additional Measurement Technology

The ATS 200 is able to re-check the precise geometry of the cell after machining. This is done by means of a tactile sensor. The measured values are clearly displayed to the operator in the software.

Tactile Sensor

The tactile sensor has a low contact pressure so as not to damage the lens and its coating. The diameter of the sensor’s ball tip can be chosen so that the surface contact force is minimized. The sensor can easily be exchanged to handle different measurement tasks. In order to determine the manufactured thickness of the lens cell in addition to the diameter, a sensor with an angled ball tip can be used.

The measurement accuracy of the sensor is about 0.5 \( \mu \text{m} \); its repeatability is a bit less. During a typical machining cycle, the actual dimensions of the cell are measured once more before the final finishing. Then the cutting parameters are optimized so that the target accuracy is safely achieved.

Optical Distance Sensors

In addition to the tactile sensor, the machine can also be fitted with optical sensors for distance measurement. These are suitable for sensitive lenses, because there is no contact with the surface during the measurement. At the same time, the measurement accuracy is again better than the tactile sensor. Since the optical measurement technique is more sensitive than its tactile counterpart, optical sensors are particularly suitable for the final tolerance measurement.

Checking the Center Thickness with OptiSurf®

The ATS 200 is the only alignment turning station with integrated low coherence interferometer for center thicknesses measurement. It has the advantage that the distance between the lens vertex and the contact surface can be manufactured with precision both for the front side and for the rear.
The ATS 200 Software

One Software Solution for all Measuring and Manufacturing Processes

The Windows-based graphical user interface for the ATS 200 combines the operation of all machine functions with the routines used to measure the centration. A graphical editor is used to first enter the relevant dimensions of the cell that are to be machined by the system. In addition, the optical data of the lens can be entered so as to be able to measure the centration of the lens. From these data, the software calculates all the movements of the axes, both for the measurement as well as for the subsequent machining of the cell.

The software supports operation via touch screen. The operator can therefore change the cell data or production data by pressing the screen. Three permission levels make it possible to assign supervisor status to individual employees in order to make a distinction as to who can change what data in the program.

While it is possible to call individual software functions specifically, the particular advantage of the software is its support for the series process. The software actively alerts the operator to the next steps to be taken and in particular monitors the result of the adjustment and production. At the end of the whole process the software can issue a certificate with the achieved tolerances. This allows subsequent retracing of individual mounted lenses back into production.

Key Features of the ATS 200 Software

- Automatic assessment of centering error of both surfaces
- Graphical representation of the alignment process and accuracy
- Optimized travel of the axis reduces time for machining
- In-process control measurement before the final finishing
- Task oriented user guidance through the alignment process
- Certificates give information about the final accuracies of the cell
- Permission levels in three groups
- Prepared for touch screen usage

Editor to input the data of the cell
The ATS 200 is offered as a fully functional alignment turning machine with integrated measurement technology. In order to expand the application scope and also to increase the efficiency of the machine, TRIOPTICS offers various upgrades:

"Larger Workpiece Size" Upgrade

The ATS 200 can be equipped with a workpiece holder suited for the machining of diameters between 20-150 mm or 70-200 mm. To add flexibility regarding the machinable diameter, this upgrade increases the machining area to larger workpieces from 20 to 200 mm in diameter and a maximum cell height of 100 mm. The linear axis of the machine can be extended and be carefully calibrated with high accuracy so as to ensure the accuracy even for large workpieces.

Facts about the "Large workpiece sizes" upgrade

- Maximum diameter of the workpiece: 200 mm (minimum 20 mm)
- Maximum height of the workpiece: 100 mm

"Second Autocollimator" Upgrade

With the "second autocollimator" upgrade it is possible to measure two lens surfaces simultaneously. The second autocollimator is used below the hollow spindle and is therefore ideally suited to measuring the bottom lens surface, which is necessary with infrared lenses in particular.

Extension of the measuring range with the "Second autocollimator" upgrade

- Measures both lens surfaces simultaneously and provides additional information about the tilt of the sample
- Allows the measurement of mounted infrared lenses in the visual non-transparent range without the use of special infrared autocollimators
- The simultaneous measurement of the front and back of a lens reduces the alignment time

"Production of Aspherical Lenses" Upgrade

If the optical axis of an aspherical lens needs to be aligned to the rotational axis of the spindle, it is necessary to expand the system. An additional sensor is integrated into the machine, adding asphere measurement functions to the software.

"Production of aspherical lenses" upgrade

- Production of the lens cell with respect to the axis of the asphere
- The optical sensor is installed on a rotary table and can be positioned perpendicular to the lens surface
- Software update for measuring aspheres

Four-Way Tool Changer

This tool holder can hold up to four tools to reduce the need for tool changes. These indexable insert tools are used in the holder supplied. The exact cutting positions of the tools are measured before machining. The high-precision clamping block incorporated into the tool changer ensures that the tool position is maintained even after many changes.
Upgrade and Accessories

Optical Distance Sensor

Depending on the selected measurement head and how easy it is to access the cell, the optical sensor can be used to measure the distance between lens vertex and contact surface with an accuracy of 0.25 µm.

Automated Head Lens Exchange

The top autocollimator is fitted with an automatic revolver to save time when exchanging head lenses.

Set for Regular Calibration

As with all high-precision alignment turning machines, the ATS 200 requires regular calibration. TRIOPTICS offers a set of alignment and measurement tools for this purpose.
The ATS 400 is currently the largest alignment turning station in the ATS range and was developed in cooperation with LT Ultra. It is especially suited to alignment turning of large workpieces. It is characterized by its ultra-stable, vertical design and the built-in OptiCentric® measurement system. The ATS 400 is unique in its class and especially suited for high-precision alignment of large workpieces with a diameter of up to 400 mm.

Main Advantages of the ATS 400:

- Unrivaled manufacturing accuracy: lens centration of better than 0.5 µm
- Combination of turning machine and the world leader OptiCentric® measurement system
- Mounted lens is measured from both sides: as a result measurement is faster and more stable and non-transparent lenses can be measured
- Additional equipment with tactile and optical sensors
- Vertical design of the ATS 400 allows for heavy samples up to 30 kg with large diameters up to 400 mm
The ATS 400 Software

- Ultra-precise axes with hydrostatic bearings, high rigidity for processing steel and Invar cells
- Intuitive, manual adjustment of the lens, because the chuck’s shift and tilt functions are separate from each other (plan/calotte principle)

The manufacturing and measurement systems are combined in the ATS 400. To achieve the highest possible manufacturing accuracy, the measurement software and the manufacturing software work in coordination with each other. The key process step is the alignment of the sample. Here, the production machine works with functions of the OptiCentric® software, ensuring a reliable and highly accurate assessment of centration errors for all individual surfaces.

Key Features of the ATS 400 Software

- Automatic assessment of centration error of both lens surfaces
- Alignment and processing of the sample based on the centration measurement
- OptiCentric® software and software of the alignment turning machine work in conjunction with each other
- Graphical representation of the alignment process and alignment accuracy
- In-process control by monitoring the camera image during machining
- Intuitive – operation is based on the measurement software
# Technical Data for ATS 200 and ATS 400

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<tr>
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<th>ATS 200*</th>
<th>ATS 400**</th>
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<tbody>
<tr>
<td><strong>Machine type</strong></td>
<td>Vertical CNC turning machine with 3 aerostatic precision axes and integrated measurement systems</td>
<td>Vertical CNC turning machine with 4 hydrostatic linear axes and an aerostatic main spindle</td>
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<tr>
<td><strong>Measurement system</strong></td>
<td>OptiCentric® optional: OptiCentric® Dual</td>
<td>OptiCentric® Dual</td>
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<tr>
<td><strong>Workpiece diameter</strong></td>
<td>20-150 mm optional 20-200 mm</td>
<td>80 – 400 mm</td>
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<td><strong>Maximum sample weight</strong></td>
<td>5 kg</td>
<td>30 kg</td>
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<td><strong>Workpiece material</strong></td>
<td>Diamond machinable non-ferrous metals (in particular brass, aluminum, NiP-coated steel)</td>
<td>Diamond machinable non-ferrous metals (in particular brass, aluminum, NiP-coated steel) Also: low-alloy steels (such as EC80) and Invar36®</td>
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<td><strong>Achromats</strong></td>
<td>Yes</td>
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<td><strong>IR lenses</strong></td>
<td>Yes, by infrared measurement head or OptiCentric® Dual</td>
<td>Yes, by infrared measurement head or OptiCentric® Dual</td>
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<td><strong>Aspheres</strong></td>
<td>Yes, optional</td>
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<tr>
<td><strong>Remaining centration error after machining</strong></td>
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<td>&lt; 0,5 µm</td>
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<tr>
<td><strong>Concentricity of the cell after machining</strong></td>
<td>&lt; 1 µm</td>
<td>&lt; 0,5 µm</td>
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* All figures for brass cells with a diameter of 150 mm
** All figures for brass cells with a diameter of 400 mm
OptiCentric® Systems measure and align all types of lenses with diameters from 0.5 to 800 mm with submicron accuracy.

Key features of OptiCentric® Systems

- Measuring, aligning & inspecting lenses in VIS, MWIR and LWIR
- Fast active-alignment with respect to a customer specific axis with Smart Align saves the time consuming reference alignment
- Upgrades allow for measurement of center thickness and air gaps, EFL, BFL, FFL and on axis MTF
- One integrated system, OptiCentric® Software controls the entire system
- Automatic exchange of head lenses:
  - Unlimited measurement range
  - Magnification appropriate to the sample
  - Minimizes travel of the measurement head