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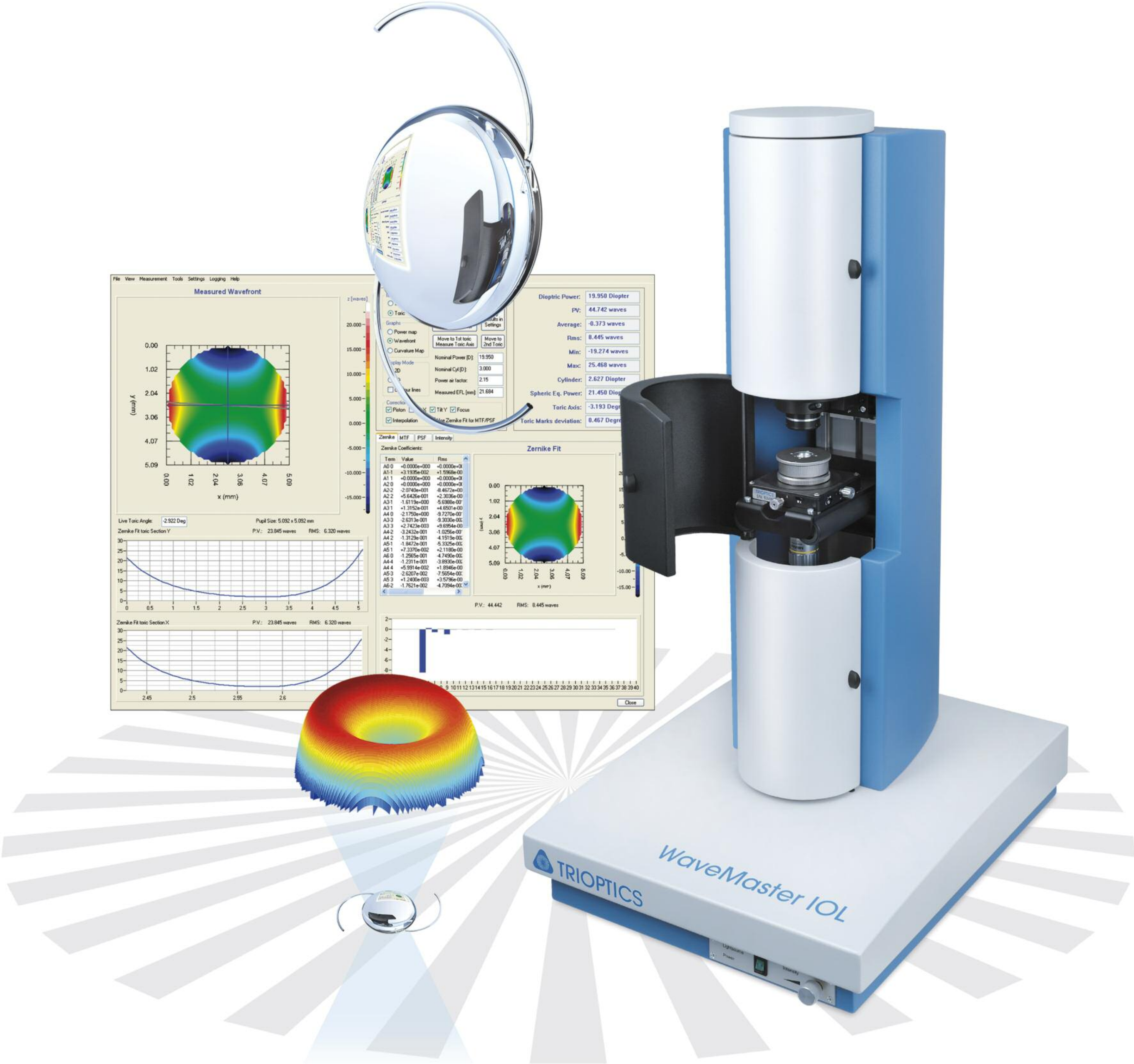
WaveMaster® IOL

Fast and Accurate Intraocular Lens Tester



Surface & Wavefront Metrology

AspheroMaster®

WaveMaster®

WaveMaster®IOL
Fast and accurate intraocular lens tester

WaveMaster®IOL is an instrument providing real time analysis of intraocular lenses (IOL) by measuring and analyzing the wavefront with high speed and accuracy. The ultra-accurate wavefront mapping enables analysis of most complicated lenses with spherical, aspheric or toric shape. Among many other parameters **WaveMaster®IOL** provides results for

- Diopter power as well as high resolution power mapping of the complete lens aperture
- Lower and higher orders of lens aberrations
- Modulation Transfer Function (MTF) and Point Spread Function (PSF)
- Effective Focal Length (EFL)
- Cylinder

Various wavefront sensors with different spatial resolutions and available accessories allow **WaveMaster®IOL** to be used in different environments like production sites or research and development laboratories. In combination with a temperature stabilized model eye all types of IOL can be characterized in situ according to EN/ISO 11979. It is also possible to simply measure the lenses in air.

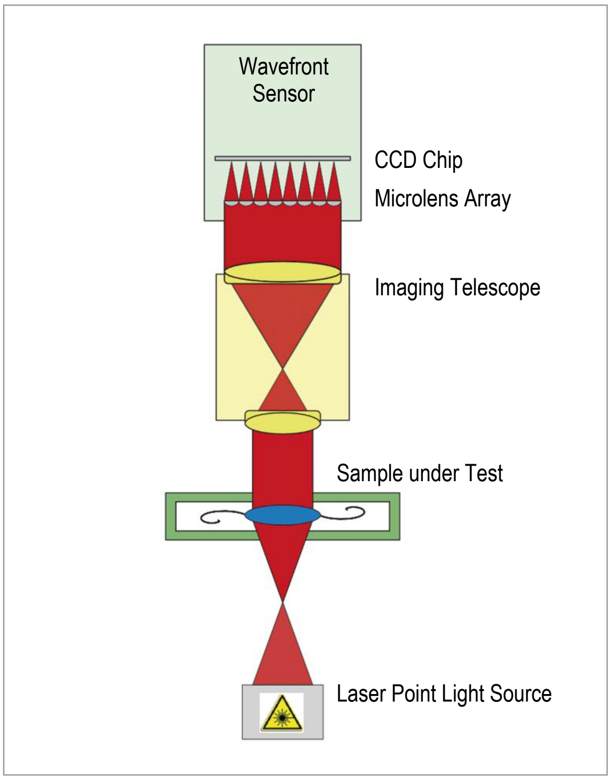
The software provides various ways of displaying the results. It includes extended analysis features and data saving options. In addition theoretical data can be loaded and compared in real time with measurements.

For ultra-fast measurement of IOL in high volume production, an automated tray system with multiple lens seats and an attachable model eye is available.

Setup

WaveMaster®IOL is based on a Shack-Hartmann wavefront sensor measurement system in infinite conjugate setup. Wavefront sensors measure aberrations which are introduced to a wavefront while passing through any kind of optical material, or lens.

In the infinite conjugate setup a point light source is placed in the focal plane of the sample under test. A telescope images the exit pupil of the sample under test onto the wavefront sensor. At the same time the image is magnified in order to use the full area of the wavefront sensor to guarantee the highest spatial resolution.



Infinite conjugate setup of the wavefront measurement system

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System components

Wavefront sensor

The standard design of a Shack-Hartmann sensor mainly consists of a CCD camera which is placed in the focal plane of a microlens array. An incoming wavefront is sampled by the lenses of the microlens array and the foci form a spot pattern on the camera which would be evenly spaced in the case of a plane wavefront. Any aberration introduced by the sample lens leads to a curvature of the wavefront thus resulting in small local wavefront tilts. These induce a measurable shift of each focus spot position. An integration of the obtained slope information allows for reconstruction of the wavefront profile to be reconstructed with high accuracy.

Using state-of-the-art computers this wavefront reconstruction can be done within the CCD camera frame rate i.e., within fractions of a second even if microlens arrays with a large number of lenses are used to obtain high spatial resolution.

Light source

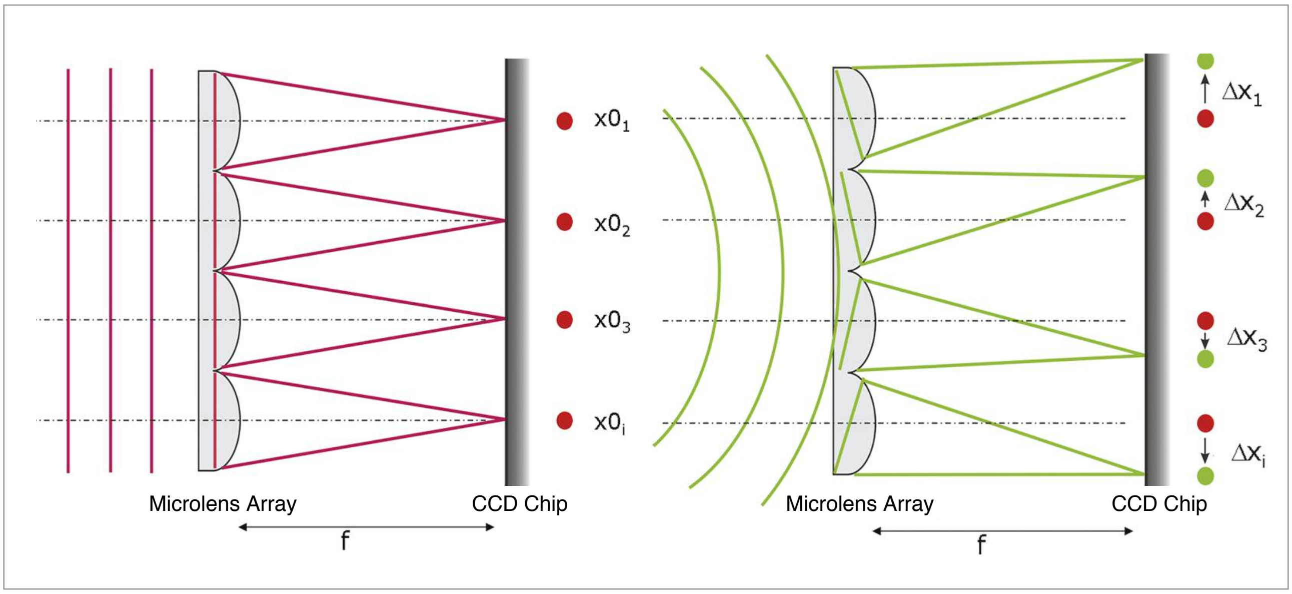
The point light source consists of a stabilized monochromatic laser light source with an absolute wavefront error < $\lambda/15$.
It is available with different wavelengths, numerical apertures and working distances. A kinematic mount allows for easy change.
The point light source is placed on an automatic high precision linear focusing stage.

Sample holder

The sample holder can be adapted to the requirements of the individual IOL measurement task.

In-air measurement

Single IOL sample jigs which allow the lenses to be measured in air can be used with WaveMaster® IOL. The lenses are placed in the jig which is then inserted into the holder base of the instrument. Thanks to the high precision holder base no extended sample alignment is necessary. Due to the easy handling, lenses can be exchanged very quickly resulting in a high throughput.



Measurement principle of the Shack-Hartmann wavefront sensor

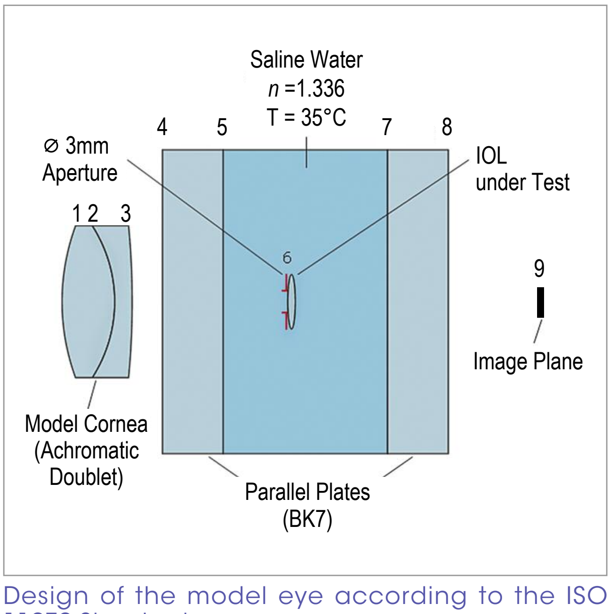
In-situ measurement

When in-situ measurements are required a model eye can be used. It fits into the high precision holder base of the instrument and is easily exchangeable with the single lens jigs.

The model eye has been designed to simulate the effect of the real human eye during measurements of IOL and is defined in the ISO 11979 Standard.
It is composed of two parallel plates delimitating an area filled with saline solution. The IOL is placed at a specific position between these two plates on a sample holder including the aperture stop. An achromatic doublet simulates the eye cornea. The complete model eye is held at a constant temperature of 35°C.

The aperture size can be changed to suit measurement requirements. By default it is Ø = 3 mm.

The model cornea can be removed easily to allow the optical power of the IOL to be measured.



Design of the model eye according to the ISO 11979 Standard

The **WaveMaster®IOL** with the model eye as the sample holder for in-situ measurement

High volume production testing

In case of testing in a high volume production environment, the system can be factory configured with a tray system which allows a multitude of IOL to be measured fully automatically. This tray system which contains a fully motorized high precision XY linear stage is suitable for in-air and in-situ measurements including the model eye.

During the measurement an automatic classification of all IOL in different quality classes is done according to user defined pass fail criteria. A classification map is displayed at the end of each tray measurement allowing the lenses to be easily sorted.

Operating Principle

Optimized for simplicity of use and high accuracy, WaveMaster® IOL provides a fast and accurate tool for testing intraocular lenses in a research and development environment as well as in a production environment.

The wavefront is measured and analyzed with frame rates of up to 16 Hz and provides real time power map, PSF and MTF as well as analysis of the lower and higher order lens aberrations. In addition, WaveMaster® IOL also determines the EFL and average diopter power. Already during the measurement a real time comparison with design or reference data can be performed.
Since simultaneous measurements of different aperture diameters are possible the IOL can be analyzed at e.g. Ø = 3 mm and Ø= 6 mm at the same time without changing the instrument setup.

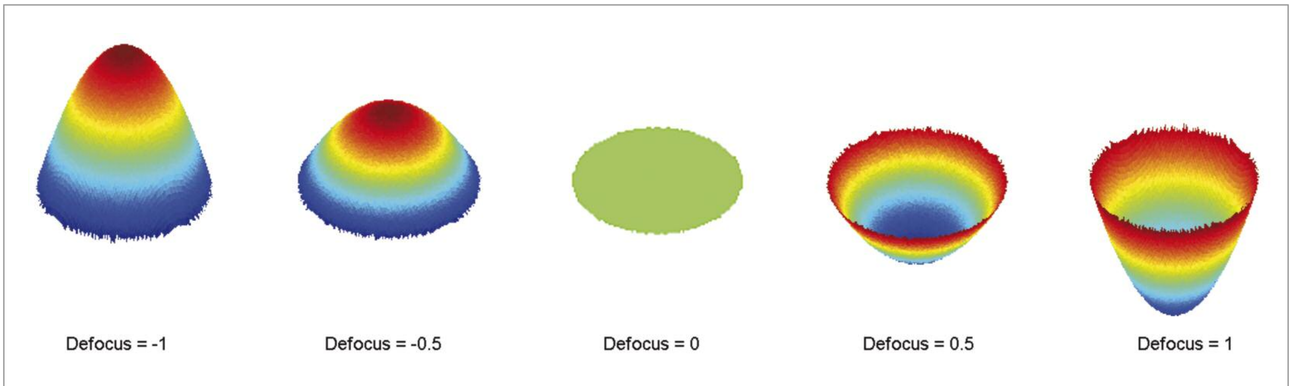
All measurements on IOL can be done in-air or in-situ. Hardware as well as software support an easy and fast change between the different measurement conditions.
On the software side this is enabled by the possibility to save and load individual measurement settings files, on the hardware side by using the high precision sample holder. In addition, alignment error compensation and automatic focusing allow easy and fast sample setup.
When measuring large numbers of the same type of IOL, statistic functions in the software are available.

Diopter and power map

The diopter power of an IOL is defined as the reciprocal of the reduced paraxial focal length in aqueous humor. From the measured effective focal length of the IOL, the power can be determined directly when the measurement is made in situ.

When measuring in air, the WaveMaster® IOL software converts the diopter power of the IOL for in-situ conditions taking the design conversion factor of the lens into account. Measuring in air leads to easier handling of the lenses and fast throughput in production conditions for example when using a tray with several tens of IOL.

In the power map the local effective focal length for each point of the aperture of the IOL is displayed. It is directly deduced from the measured wavefront.



By measuring the wavefront defocus coefficients, the EFL and diopter power of the IOL can be easily determined

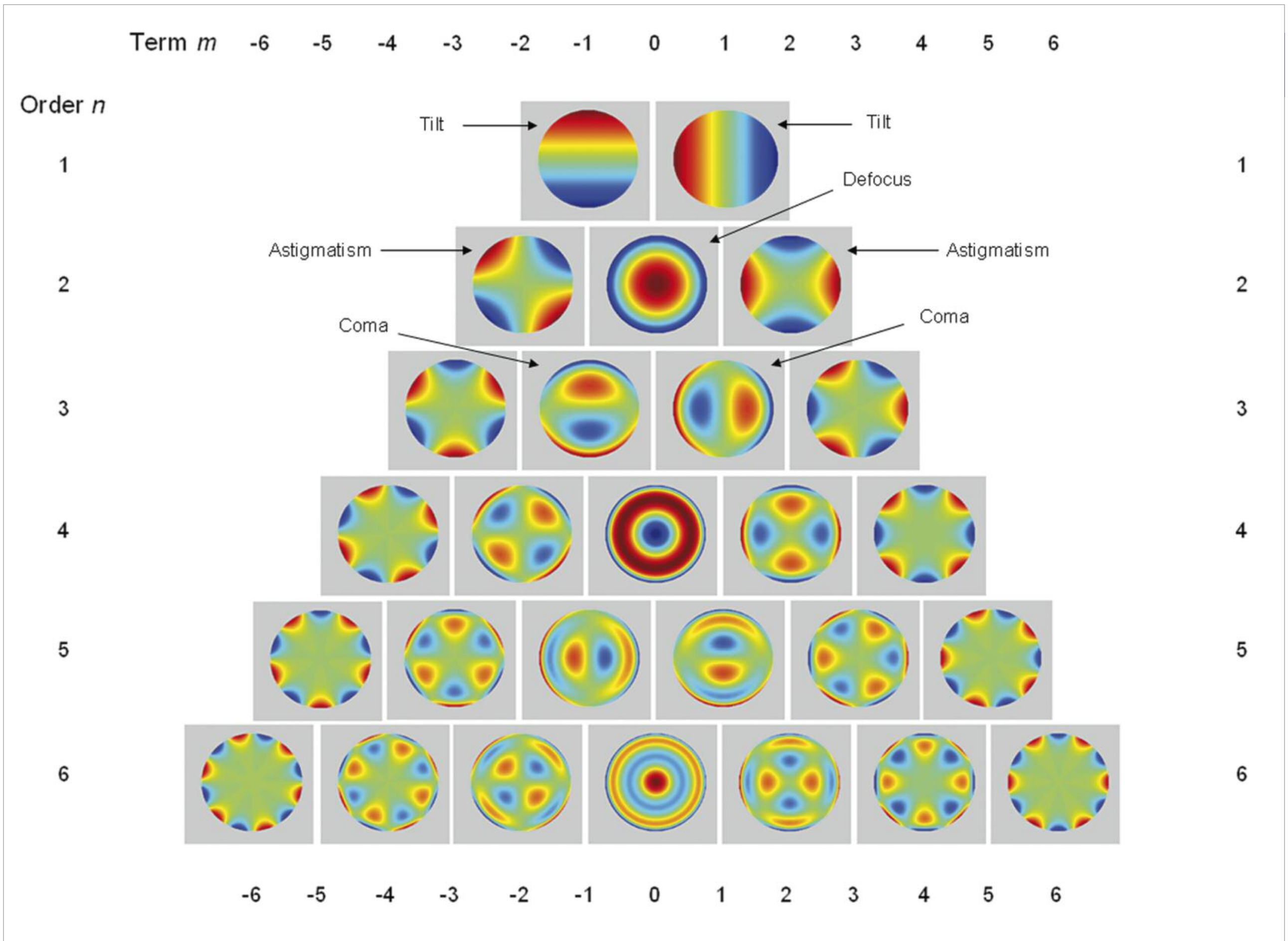
PSF and MTF

The Modulation Transfer Function (MTF) is a parameter that objectively describes the performance of optical imaging systems by testing the ability of an optical system to transfer the details of an object to the image in terms of contrast. It has the value 1 for a perfect contrast reproduction and the value 0 for a system unable to produce any image contrast.

PSF as well as MTF can be calculated directly from the measured wavefront and are displayed in real time.

Lens aberrations

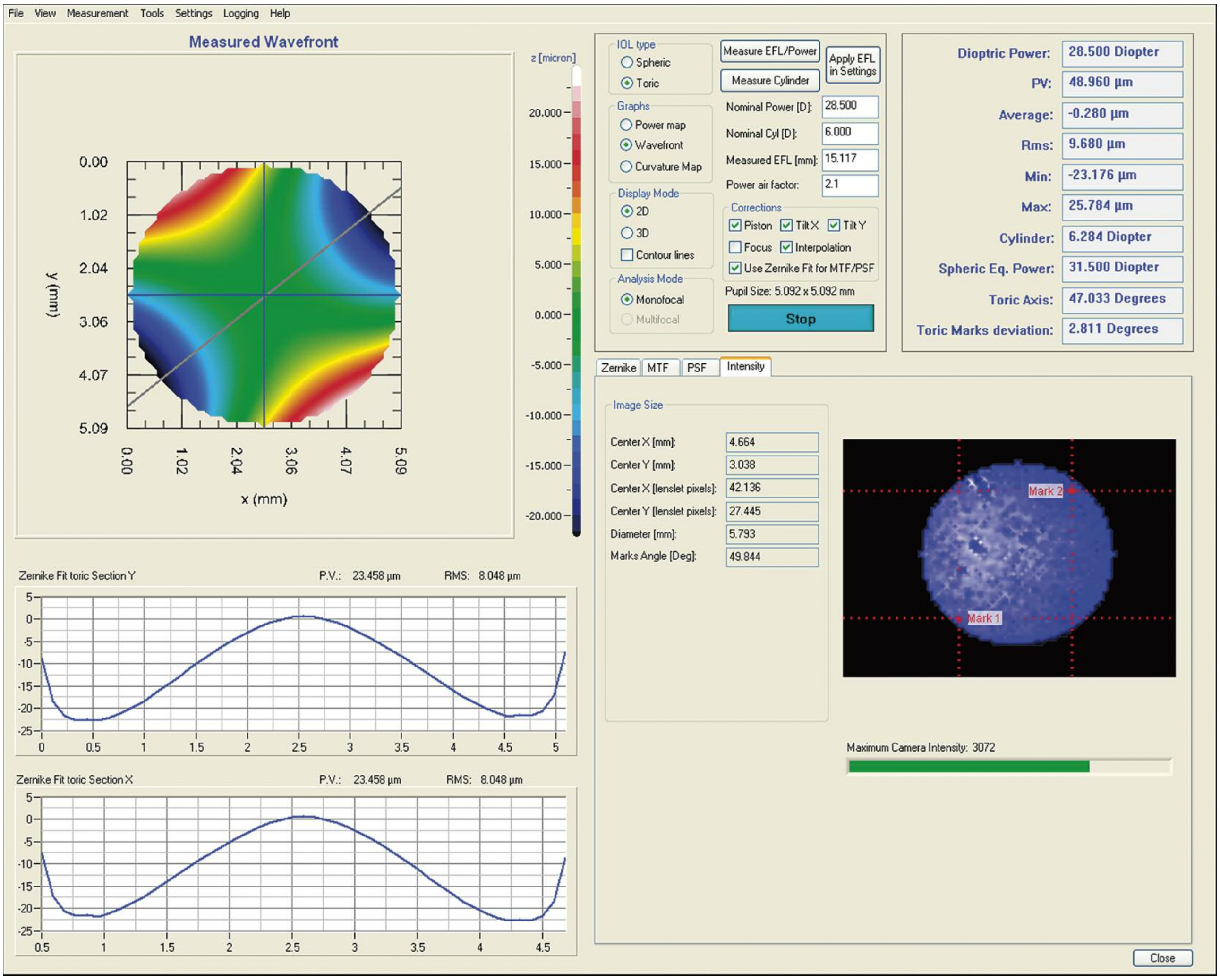
The measured wavefront can be decomposed into a linear combination of polynomials of the Zernike or Seidel series which describe typical optical properties and errors of a lens as e.g. coma and astigmatism or spherical aberrations. This allows for real time measurement and comparison of lower and higher order lens aberrations of the IOL.



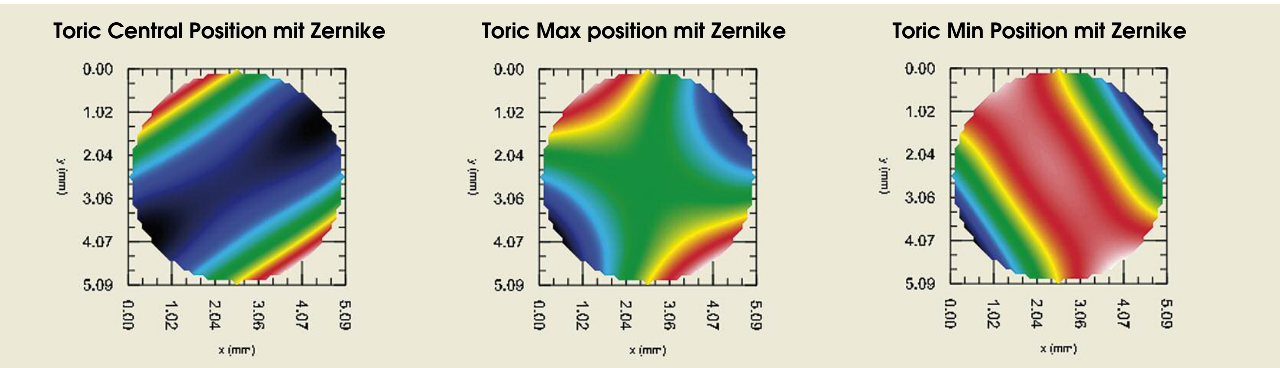
First 6 orders of the Zernike coefficients

Toric IOL measurement

The WaveMaster® IOL makes it possible to measure toric IOLs by automatically finding the different focusing planes along the two crossed meridian of the lens. From these different wavefronts, the software calculates the cylinder of the lens and estimates the angle of the toric axis. In addition, by setting the positions of the toric marks in the intensity view, the operator can determine the deviation between the toric axis and the toric marks.



Toric axis determination



Wavefronts obtained for three typical positions of a toric IOL

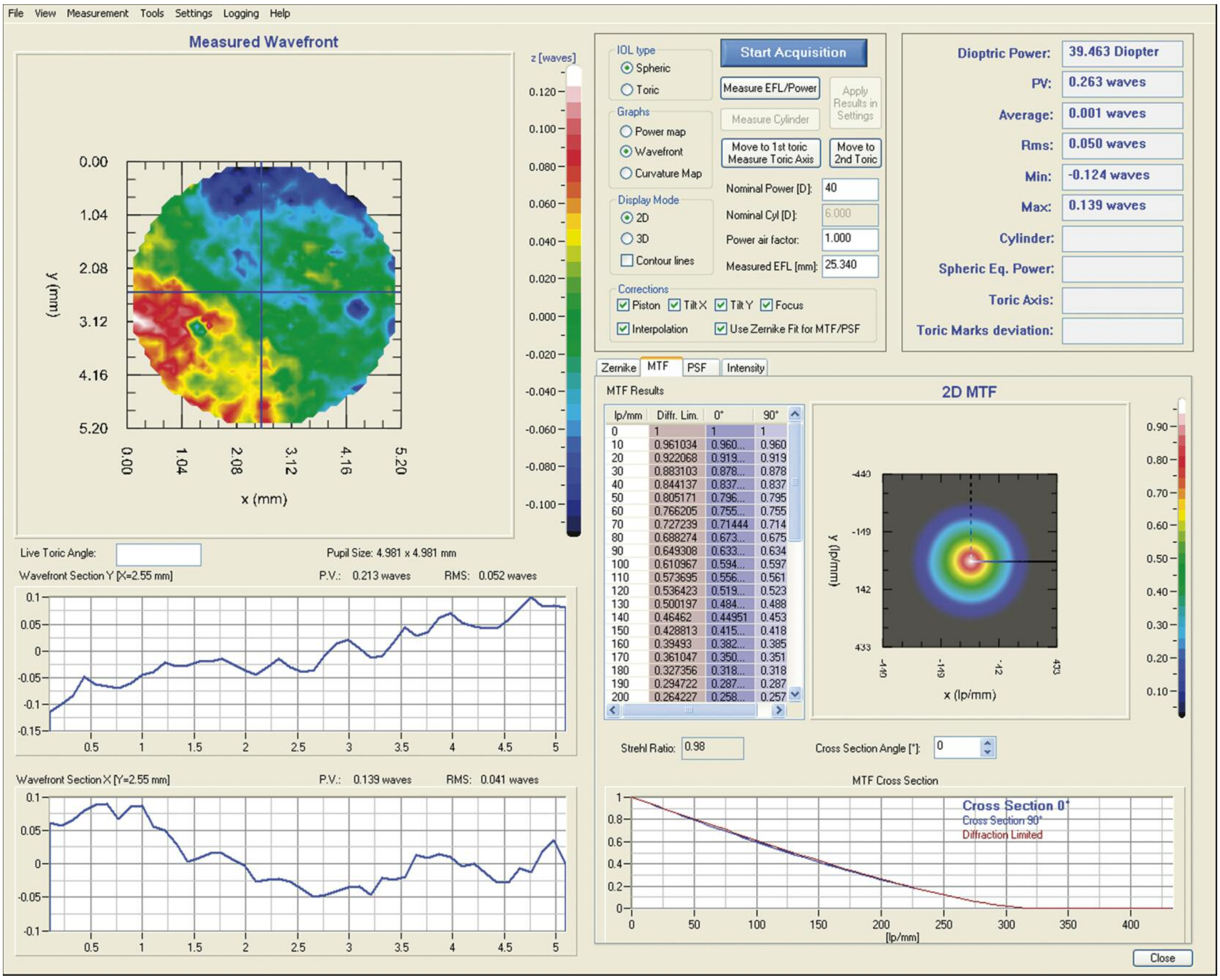
Software

The advanced software is designed to work with Windows operating systems and features easy, intuitive operation to meet optical test requirements. It offers a high level of speed and accuracy and provides consistent, reliable results.

All aspects of data acquisition starting with the powerful autofocus system, data calculation, calibration and the display of data are under software control and fully automated. The software package provides menu-driven operator guidance and advanced data management.

Wavefront acquisition and display

- Absolute or relative measurement
- Subtraction of background illumination
- Real time display of
  - 2D and 3D wavefront
  - Peak-to-Valley and Root-Mean-Square Values
  - Intensity
  - Slope data
  - Raw camera image
- Real time correction of sample misalignment (tilt and defocus)
- Available units: µm or λ
- Frame rate up to 16 Hz



WaveMaster®IOL Software - Wavefront and calculation of MTF

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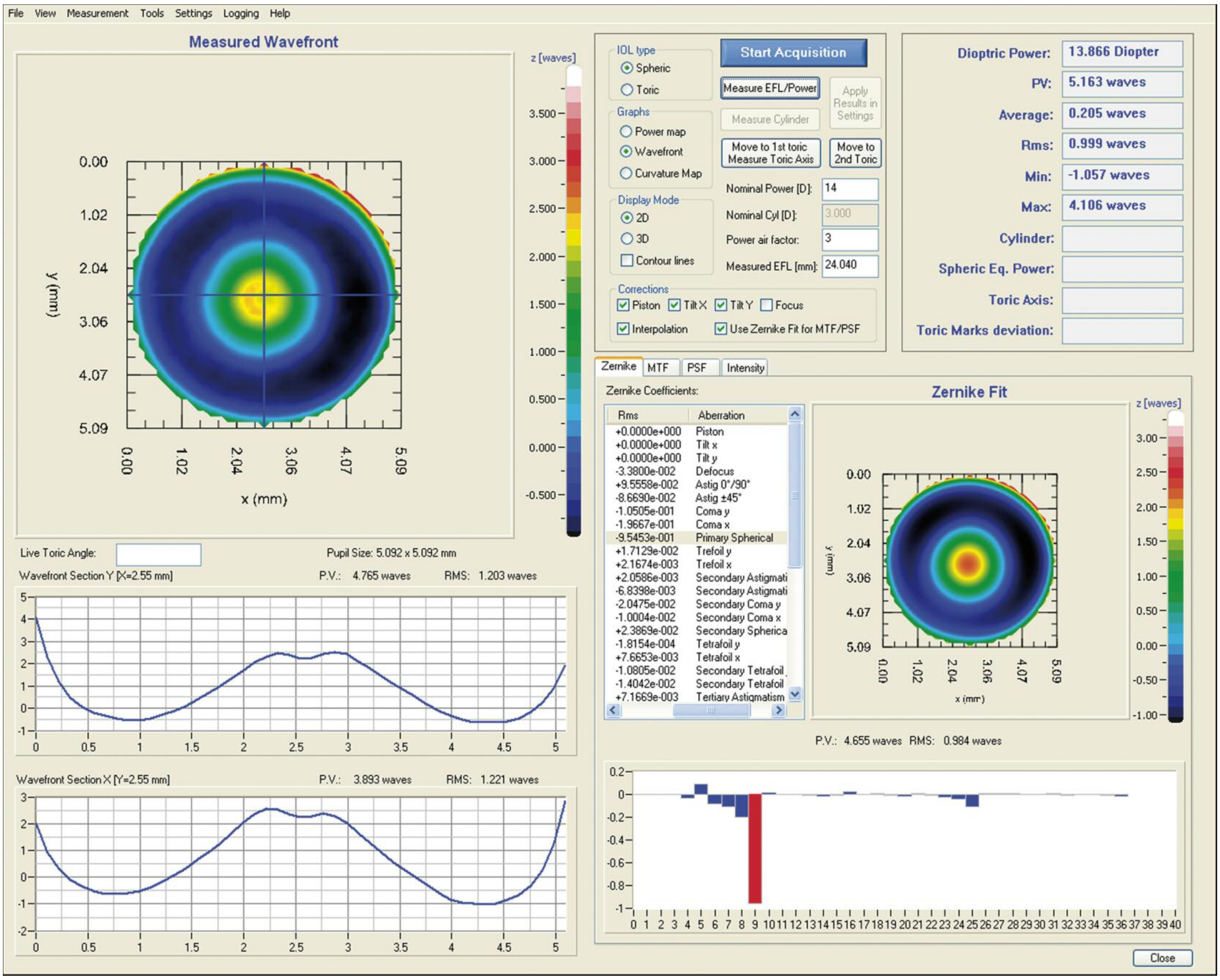
Intraocular lens measurement

- Diopter power and power map
  - Real time calculation and 2D and 3D display
  - Customized zonal display of power-map
- EFL measurement and display
- MTF and PSF
  - Real time calculation and 2D and 3D display
  - Real time numerical and graphical (2D and 3D) display
- Lower and higher lens aberration (Zernike and Seidel)
  - Real time aberration analysis
  - Real time numerical and graphical (2D and 3D) display of aberration coefficients
- Pass/Fail classification according to user defined criteria
- Real time comparison of measurement results with design data

Data saving and documentation

- Measurement certificate showing
  - Graphical and numerical display of all measurement results
  - Measurement conditions and sample related information
- Results can be saved in various formats to allow for further analysis with external software
- Detailed measurement settings can be saved into separate files and reloaded



WaveMaster®IOL Software - Wavefront and Aberration evaluation

Technical Data

- Aperture diameter: 0.5 to 15 x 15 mm
- Number of lenslets: up to 140 x 140
- Power range:
  - Direct measurement
    - In air: >+4D, < -10 D
    - In situ: >+10 D, < -30 D
  - Collimated illumination
    - In air: < 3 D, > -3 D
    - In situ: < 1 D, > -1 D
  - With model cornea
    - In situ: no limitations
- Power absolute accuracy: 0.1 to 0.3 %
- Power resolution: 0.01 D
- Power map lateral resolution: 20 µm for a 3 mm aperture
- MTF absolute accuracy: 2%
- Wavefront measurement absolute (relative) accuracy rms: <λ/20 (λ /50)
- Measurement time for 1 IOL including Power, MTF and aberrations: 5 sec
- Wavelength: 532 nm
- Focus position accuracy: 1.5 µm

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