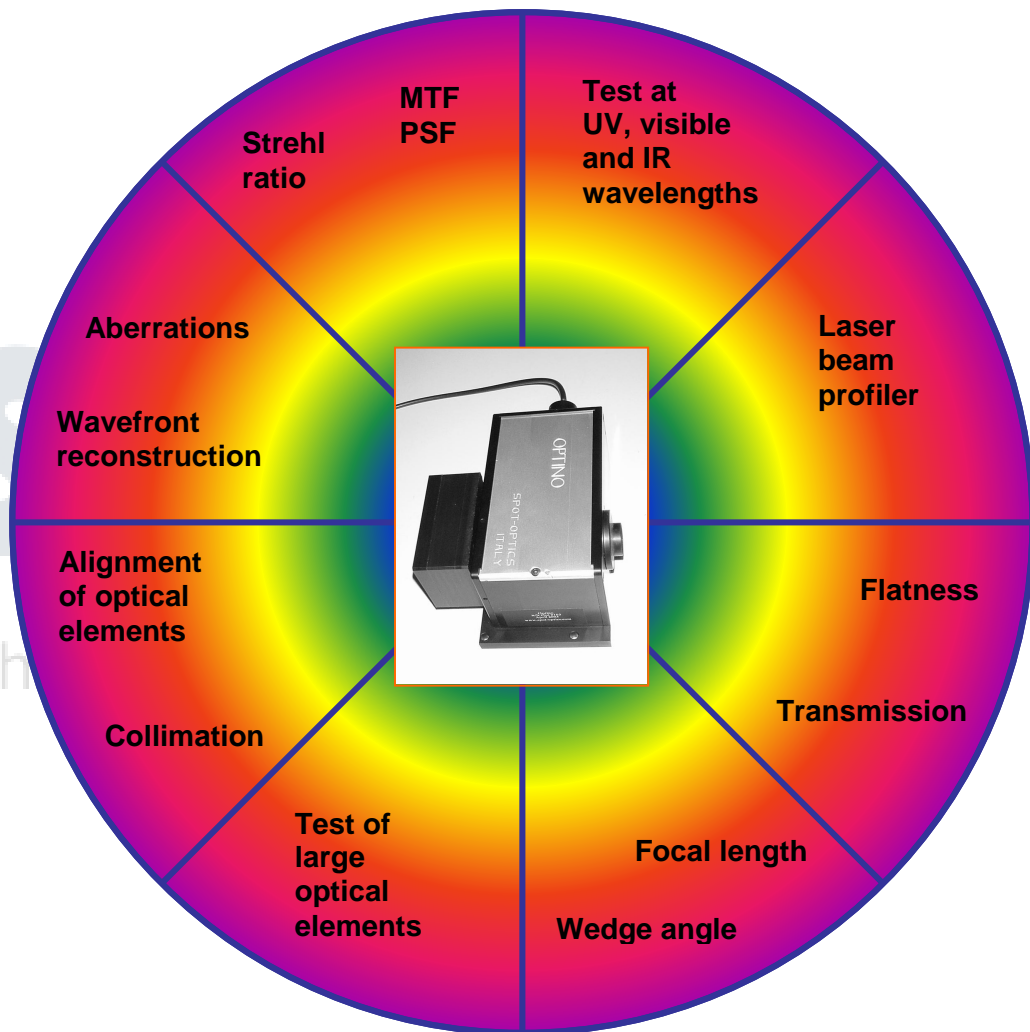


Optino

Shack-Hartmann wavefront sensor for the laboratory

Flexibility and versatility – at an affordable cost



Optino

Spot-optics

The software people for optics

We sharpen your image

Your application

Precise testing of optical elements

- § Lenses, aspheric lenses
- § Prisms
- § Spherical mirrors, aspherical mirrors, flat mirrors
- § Filters
- § Contact lenses, ophthalmic lenses
- § Complex optical systems
- § Heads Up Display (HUDs) systems
- § Lapping plates
- § Silicon wafers
- § Lasers



Features

NOT ONLY A WAVEFRONT SENSOR, BUT A COMPLETE SUITE OF OPTICAL TESTING TOOLS FOR YOUR LABORATORY AND MANUFACTURING ENVIRONMENT

- § Aberrations
- § Wavefront or surface reconstruction
- § Transmission of optical elements
- § Flatness
- § Wedge angle
- § Alignment of complex optical systems
- § Collimation
- § Focal length
- § MTF
- § PSF
- § Strehl ratio
- § Laser beam: quality, power in bucket, width, position and shape, waist, divergence

The 3 standard configurations of Optino

Optino Easy Sensor (Optino Es)

§ This is the basic system, with a fixed collimator for the light source. It has all the basic functions you will need for optical analysis, including a fiber-optic light source.

Optino Professional (Optino Pro)

§ Like *Optino Easy Sensor*, but with a motorized collimator and advanced software functions, and a higher degree of automation.

Optino Engineering Edition (Optino EE)

§ Like *Optino Pro*, but optimized for the manufacturing environment. It can be used in a feed back loop, and can measure the optical quality with a frequency of about 4Hz. Up to 30Hz frequency available.

Sensoft

§ All the three versions come with *Sensoft*, the Shack-Hartmann wavefront sensor control and analysis software. The version of *Sensoft* coming with *Optino Pro* and *Optino EE* contains some additional features with respect to *Optino Es*. The package is available under any Windows operating system (ME/2000/XP). For software details see tables in the next pages.

Basic kit

§ All three versions can be used with a **basic kit** to get you started straightaway. With this kit, you can straightaway use Optino for testing an f/6 mirror or lens. The spherical and flat mirrors can be used for other tests as well.

Custom solutions

§ Optino has a very high degree of modularity both in hardware and in software. This means that it can be easily adapted to your special requirements. More than 20 years of experience in the field of Shack-Hartmann wavefront sensors, optical design, optical alignment, software design and development are at your service when we discuss with you the best configuration for you.

Optino: the wavefront sensor with the most advanced functions

Enhanced Features

Zernike Polynomials	<ul style="list-style-type: none">§ Selection among 3 types of Zernike terms (Standard, Fringe, Annular) Seidel aberration terms can be also fit to data§ 70 Zernike terms can be fit to the data
Wavelength Range	<ul style="list-style-type: none">§ Test at visible wavelengths: 0.35-1.1 μ (with standard camera)§ Test at UV wavelengths: 0.193-1.1 μ§ Test at IR wavelengths: 90.4-1.8 μ
Cameras	<ul style="list-style-type: none">§ Camera is mounted externally to the instrument and can be easily changed by user§ Cooled or uncooled cameras for working with white light sources (visible) can be mounted§ UV and IR sensitive cameras can be mounted§ User selected (on request)
Analysis	<ul style="list-style-type: none">§ Automatic control of optimum exposure time§ Average of frames to reduce noise due to air-turbulence effects§ Average of coefficients obtained from SH analysis to improve the accuracy of measurements§ Continuous analysis loop
Modularity	<ul style="list-style-type: none">§ Test large optical elements by using our motorized Beam-expanders§ External calibration unit§ High modularity in hardware and software allows us to offer you the custom solution closest to your requirements
Manufacturing environment	<ul style="list-style-type: none">§ Work in closed loop with the production machine in the manufacturing environment
Simulations	<ul style="list-style-type: none">§ Generation of Zernike wavefronts§ Diffraction computations based on analytic theory: MTF, PSF and EE profile
Interface	<ul style="list-style-type: none">§ Compatibility with Zemax

Diagnostics

Output	§ More than 50 graphics make the interpretation of your results easy: 3D and contour plot of wavefront and mirror surface, spot diagram, EE profile and distribution of residuals over the pupil, MTF,PSF and EE profile from spot diagrams
Alignment	§ On-line alignment of complex optical systems (guided by our software - both magnitude and direction)
	§ Given the parameters of the optical system, Sensoft suggests the changes required to correct coma for composite optical system
Collimation	§ On-line collimation of complex optical system (guided by our software - both magnitude and direction)
Spherical Aberration	§ Identification of correct spacing between the elements of a complex optical system (using the measured spherical aberration)
Surface resolution	§ Surface details and defects with precision of 5 nm can be identified from the contour plots of the wavefront, as well as problems due to the mounting
	§ Real-time display of profile of a group of spots can be useful to identify local defects or zones with different reflectivity on the surface
	§ Distribution of flux of spots over the pupil can be also used to identify zones with different reflectivity on the surface

The software people for optics

Optino: Summary of features

Easy sensor

Wavefront analyzer with all the functions you need, at a surprisingly affordable price

- § 15 different test configurations
- § Fast-readout 1Kx1K camera with no interlacing
- § Fixed collimator
- § Basic Shack-Hartmann analysis: Zernike polynomial coefficients and wavefront, Strehl Ratio etc.
- § Software indication for correcting measured coma and spherical aberration
- § Real-time tilt adjustment of reference and mirror CCD frames, with graphical indication by software
- § Real-time tilt adjustment of focus of element being tested, with graphical indication by software
- § Image analysis
- § Computation of MTF, PSF and EE from Shack-Hartmann data (optional)
- § Simulations (optional)

Professional version

Wavefront analyzer with advanced functions

All features of Easy Sensor

- § Motorized collimator
- § Automatic focus of collimator
- § Advanced SH analysis
- § Advanced image analysis
- § Average of SH CCD frames
- § Average of coefficients obtained from SH analysis
- § Continuous SH analysis Loop (5 frames per second)

Engineering Edition

Most complete, with closed loop operation for manufacturing

All features of Pro version

- § Feed back loop to manufacturing system based on tolerances of computed Zernike aberrations or MTF
- § Automatic control of light intensity for optimum exposure

Optino: working in a closed loop in the manufacturing environment

One important feature common to all the Optino/Sensoft versions is the possibility to compute the SH analysis in a continuous loop. Available only with the Optino EE version and especially useful when Optino is working in the manufacturing environment is the possibility to **close the loop** for the manufacturing of optical elements. During the continuous analysis loop, Sensoft can communicate the aberrations coefficients to the machine manufacturing the optical element. A simple communication protocol has been defined that can be adapted to any manufacturing environment on request.

During the continuous loop, different graphs can be displayed.

- § surface/wavefront contour map
- § surface/wavefront 3D map
- § Zernike coefficients (choice among 3 series of Zernike polynomials)
- § spot diagram
- § distribution of residuals over the pupil
- § MTF

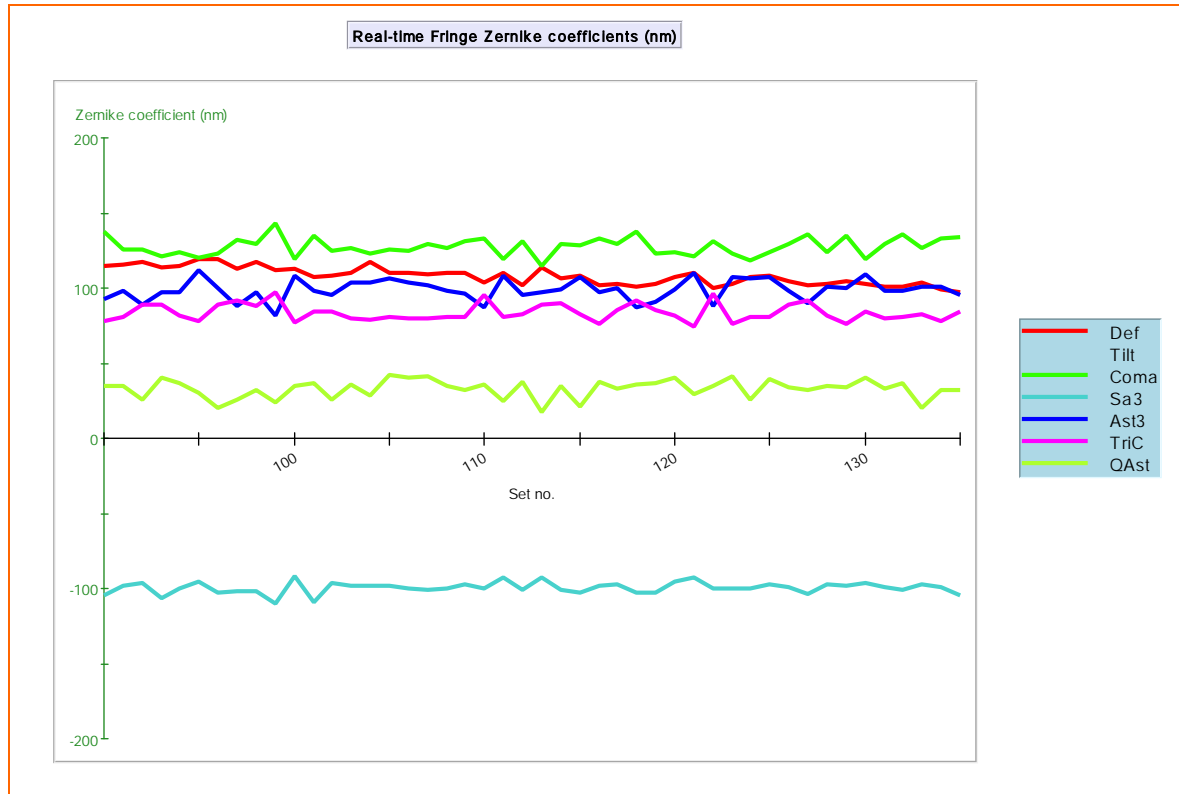
The SH image can be displayed together with any of the graphs above, to check that the optical setup during the test is maintained aligned with the reference setup.

We just mention some of the advantages of using the continuous analysis loop in the table below.

Feature	Graphs
Check the repeatability of the results from the analysis	Surface/wavefront contour and 3D, Zernike coefficients
Minimize the aberrations present in the system	Zernike coefficients, Spot diagram, Surface/wavefront contour and 3D
Check if the details on the surface are real if they maintain their orientation and structure during the loop	Surface/wavefront contour and 3D
Minimize the effect of air turbulence in the test room	Residual plot

An example of the Fringe Zernike coefficients is given in the next page.

Example of measurement of Fringe Zernike coefficients in a loop of 60 measurements



The software people for optics

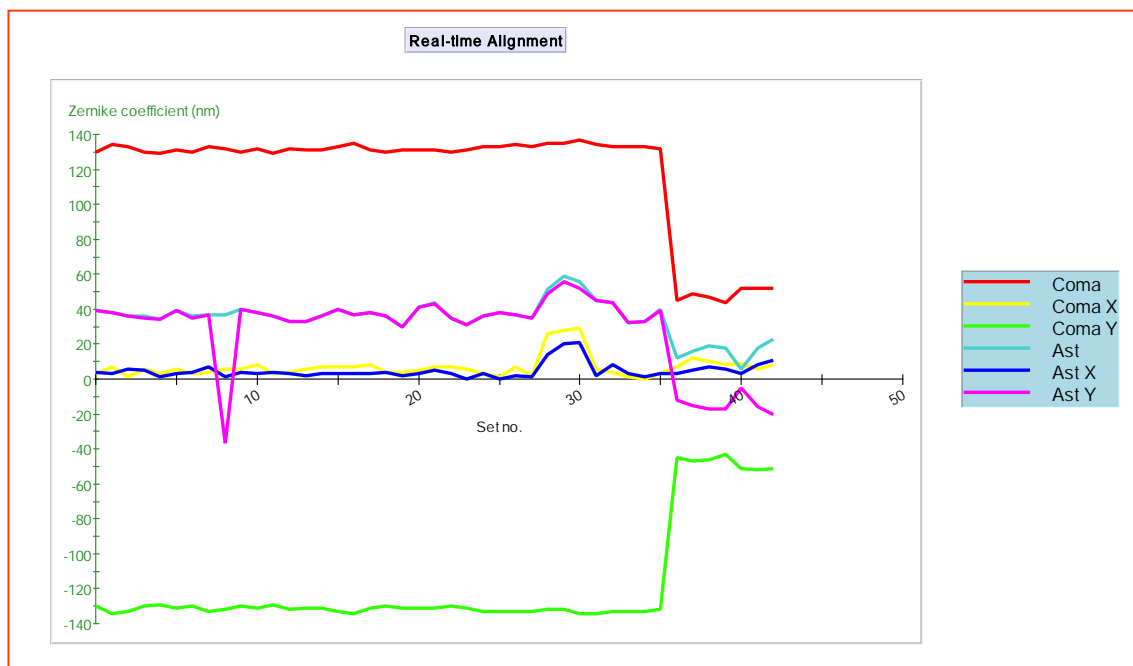
On-line alignment of complex optical systems with Optino

With Optino/Sensoft the alignment of complex optical systems is made extremely easy.

The alignment is achieved by monitoring the coma and astigmatism of the optical system under test in a continuous loop. The individual (x, y) components of coma and astigmatism as well as the total coefficients are displayed. The optimization can be done for one component at a time, as the software allows hiding from the graphs any component that is not of interest.

The optimal alignment is achieved when all of the components converge towards the 0 along the x-axis.

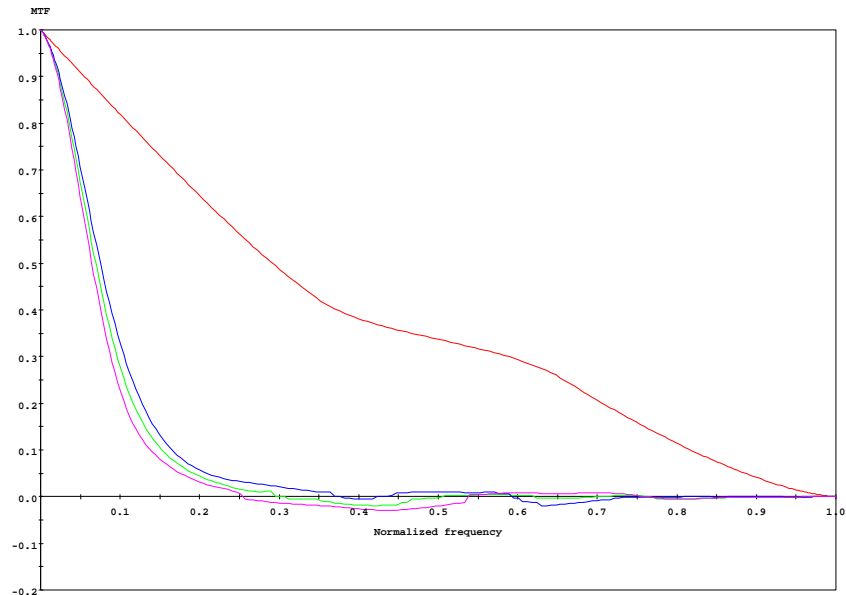
An example of the adjustment that is possible to achieve with the on-line alignment is given in the graph below.



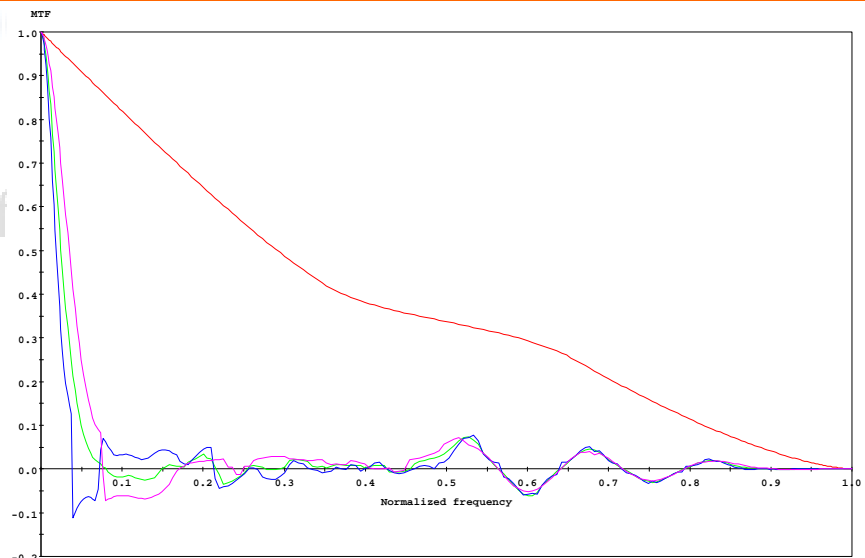
Computation of MTF

A unique feature of Optino/Sensoft is the possibility of computing MTF from the SH data. Not only can the total MTF be computed, but the MTF due to **any one** aberration can also be computed, as shown by the following graphs.

MTF after subtracting the contributions of 70 Zernike terms present in the data. The **blue** curve is MTF in the x-direction, the **violet** curve in the y-direction and the **green** curve is the total MTF. The theoretical system MTF (red curve) is also seen.



MTF after subtracting the contributions of tilt and defocus present in the data. The **blue** curve is MTF in the x-direction, the **violet** curve in the y-direction and the **green** curve is the total MTF. The theoretical system MTF (red curve) is also seen.



Higher order SA dominates the outer part of the curve.

Optino: test configurations

With Optino, there are 2 modes in which the optical element can be illuminated



Internal illumination

- § In the internal illumination mode, Optino is fed by a fiber that can be illuminated with the light source of your choice, e.g. a laser at 632nm or 1064nm. When used with a white-light source, a filter can be mounted in the filter-holder shown above.
- § There is a collimator and beam-splitter inside that can be changed so that you can work at the wavelength of your choice. The collimator can be collimated using an automated collimation process.
- § The internal illumination mode is more accurate and versatile

External illumination

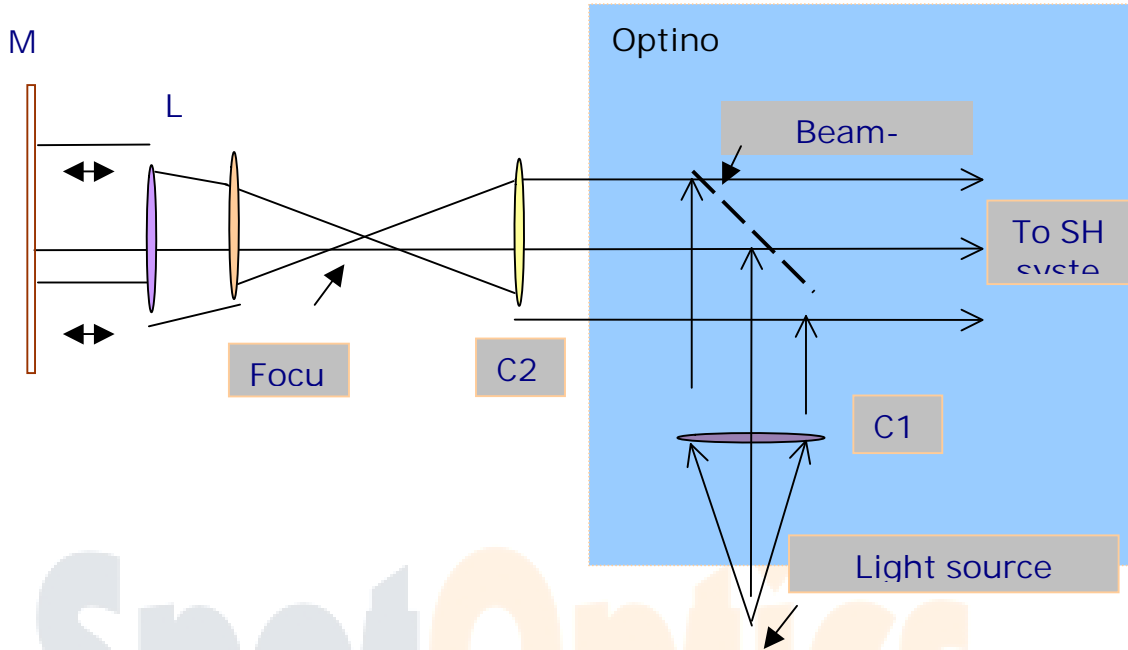
- § Similar arguments apply for the test in external illumination mode.

Optino can be used in a number of test configurations for testing almost any kind of surface. The tests are listed below. Please ask us for details.

No	Test type	Double/Single pass
1	Cassegrain Telescope	Single
2	Newtonian Telescope	Single
3	Single lens in parallel light	Single
4	Multiple-lens in parallel light	Single
5	Laser	Single
6	Concave mirror at R.C.	Single
7	Flat mirror single pass	Single
8	Flat mirror double pass	Double
9	Filter/wedge	Double
10	Single lens with collimator	Double
11	Multiple-lens with collimator	Double
12	Single lens in parallel light without collimator	Double
13	Multiple lens in parallel light without collimator	Double
14	Human eye	Double
15	Flat mirror in Ritchey-Common setup	Double

Optino: example of a test configuration

Test of multi-component lens with internal illumination



Setup

In the above configuration, light is made parallel by the collimating lens C1, and passes through the beam-splitter. It comes to a focus at F after passing through the collimator C2. It falls on a mirror M (which should be of a high quality, say $\lambda/4$, $\lambda/10$ or $\lambda/20$, depending on the accuracy required for testing the lens L).

Instrument

Optino. The collimator C2 can be changed easily to match the focal ratio of the lens L.

Output information

Along with the Zernike coefficients, wavefront and the optical quality, Sensoft gives diagnostics for correcting defocus, coma (by aligning the elements) and spherical aberration (by changing the separation between the elements). These corrections can be based on a lookup table provided by the user for any optical element in the system.

Single or double pass

Double pass.

Optino: using the beam-expander for testing large-sized elements of up to 300mm diameter

Spot-optics offers motorized beam-expanders for use with Optino

Advantages of motorized beam-expander

- § Optino gives an output beam that varies from 6.7mm (with standard camera) to 18mm (with a large format cooled camera).
- § Optino can also be used with a beam-expander to give you the beam-size of your choice (up to 23mm with BE25 and up to 58.5mm with BE60 and up to 140mm with BE150; 300mm beam provided on request).
- § All the beam-expanders are motorized, and the lenses inside can be changed according to the magnification or the wavelength desired



BE60

- § The motorized lens ensures that parallel light is obtained easily.
- § Almost any magnification can be obtained by changing the lenses L1 and L2, ensuring the maximum beam sampling of the optical element.
- § A filter can be used with the fiber optic light source. Thus the beam-expander can be used at any wavelength.
- § Diverging or converging light can be obtained to illuminate the Test optical element.

1. BE300: Maximum beam-size 300mm
2. BE150: Maximum beam-size 140mm
3. BE60 : Maximum beam-size 58.5mm
4. BE25 : Maximum beam-size 23mm
5. BEIR : For infra-red (up to 1600nm). Maximum beam-size: 23mm

Notable features of Optino

Part 1

Feature	Optino	Others
Internal calibration light source	Comes with its own internal light source for testing optical elements	Mostly can be used only with an external light source
External calibration light source	Comes with an external light source for testing optical elements	Mostly come only with an external light source
Optical elements (flat, converging or diverging) of practically any diameter can be tested	Using additional optical elements supplied by us, optical systems of practically any diameter and nature (diverging or converging) can be tested	Their limit is up to about 12mm diameter only
Motorized beam-expander	Test of elements of diameter up to 58mm using our motorized beam-expander BE60. Beam expanders of up to 300mm output beam available on request	Generally not available
Optino with cameras for the visible optimized for working at any wavelength between 350nm-1100nm	The system allows you to insert filters for performing the test at any wavelength	Most sensors do not allow this and work in white light
Optino with IR camera works between 400nm-1800nm	High-quality Vidicon camera. Works from a laptop. Economical	Generally expensive cameras are used
Motorized collimator	Guarantees parallel light for every wavelength	Most sensors do not allow this and work in white light
Modular design of instrument	Allows you flexibility in testing. Optical elements optimized for the particular wavelength can be used	Most sensors do not allow this and work in white light
Modular design of software	Allows you flexibility in testing	Most sensors do not allow this
Flexibility of changing the number of spots	Fewer spots can be used for a very fast analysis. For a detailed analysis up to 65x65 spots can be used	You need to buy different sensors. For example, for 16x16, 32x32 and 64x64
Flexibility of changing the camera	The camera is mounted externally and can be changed if required. This allows different cameras to be mounted, which are optimized for different wavelength ranges or for different sampling	Not available. The lenslet array is either glued to the camera body, or the camera is mounted inside the instrument
No thermal noise	Since the camera is mounted externally, no air turbulence is generated in the system, reducing noise	Cameras are generally mounted internally

Notable features of Optino

Part 2

Feature	Optino	Others
Portability: control from laptop	All the cameras offered with Optino can be controlled from a laptop	Standard cameras require PCI card that means the wavefront sensor can only be used from a standard PC
Mounting of SH lenslet arrays	Different Shack-Hartmann lenslet arrays can be mounted on request	In general, once you order an instrument, you cannot change the array
High dynamic range	Optino has a very wide dynamic range: e.g. hundreds of lambda of spherical aberration can be tested	Generally only a few lambda of aberration can be tested
Measurement of shape parameters (like asphericity)	Optino has a very wide dynamic range: e.g. hundreds of lambda of spherical aberration can be tested. This allows large conic coefficients to be measured	Only a few lambda of aberrations can be tested
Lasers: beam analysis, phase and intensity	Optino is the only instrument with a built-in beam-profiler, so that you get the full information on its properties: SH analysis (Zernike coefficients) and the beam-quality Beam-waist, M2, beam-divergence)	Only wavefront sensors or standard beam-profilers. Two different instruments are required
Real-time alignment: saves you time	Allows real time adjustment (alignment + focus) of reference and test CCD frames	Generally not available
Real-time collimation: saves time	Allows real-time adjustment of the focus of the optical element	Generally not available
Check for air turbulence	Can be used to quantify air-turbulence in the manufacturing environment	Not available
Focal length measurement	Very precise measurement of focal length can be made at any wavelength, allowing chromatic effects to be studied	Generally not available
Wedge angle measurement	Wedge angles can be measured	Generally not available
MTF measurement	The MTF can be measured at any wavelength	Generally not available
Turn-key approach: full system for production	Reasonable rates	Expensive
Full consultancy service provided	Reasonable rates	Expensive
Help	Very detailed Help both for the use of the instrument and the theory (Shack-Hartmann, aberrations, polynomials etc.)	Limited Help available

Advantage of wavefront sensors over interferometers

	Interferometers	Shack Hartman sensors
1	Expensive to purchase, run and maintain	Much cheaper. Hardly any moving parts
2	Large system that typically requires a large optical table	Compact system, operates on a standard rigid table
3	Require expensive vibration isolation tables	Very rugged and do not need vibration isolation tables. One can put use an ordinary table and even thump on the table without affecting the results or performance
4	Requires clean room operation	Normal laboratory cleanliness is adequate
5	Air circulation needs to be controlled	Can work even on a shop floor next to the polishing machine
6	Needs laser light	Works with either conventional light or laser light.
7	Limited to a few visible wavelengths where lasers are available	Works at any wavelength, UV to IR: 193nm to 1.7 μ . Software remains substantially same in all configurations and wavelengths
8	Limited to flats, spheres and weak aspheres	Can measure strong aspheres also (typically up to 50 λ of spherical aberration)
9	Cannot measure odd shapes	Can measure odd shapes also (like cylinders)
10	Dynamic range is limited by fringe resolution on the CCD sensor	The method inherently provides large dynamic range

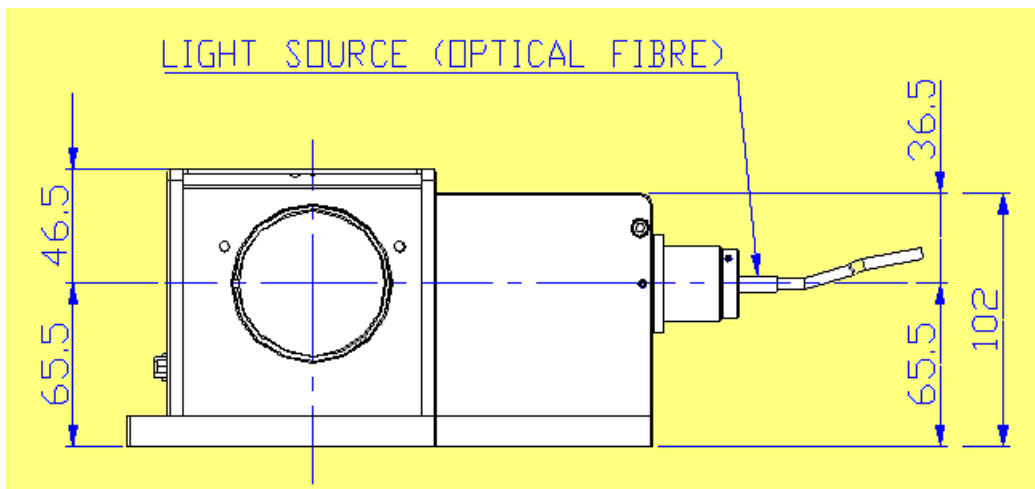
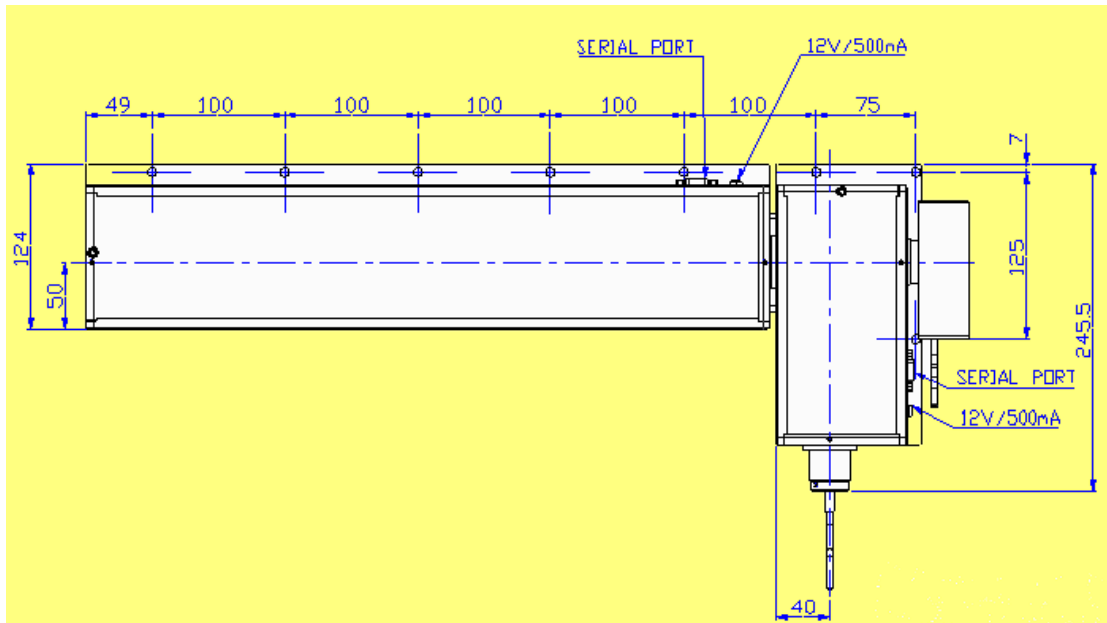
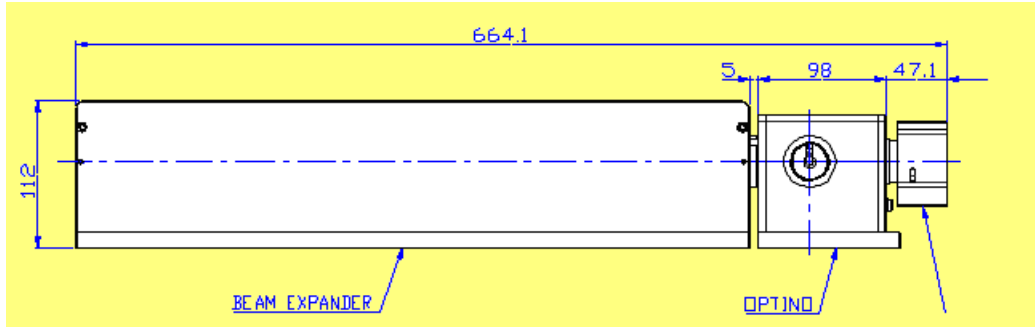
Optino: Technical Specifications

Specification	Optino
Focal ratios covered ^(1,2)	f/1 to f/300 standard
Diameter of optical element that can be tested ⁽³⁾	Practically any diameter
Diameter of lenslets ⁽⁴⁾	0.3mm
Focal length of lenslets ⁽⁵⁾	41mm
Standard sampling on the pupil ⁽⁶⁾	23x23 spots.
Maximum sampling ⁽⁷⁾	64x64 spots with large format camera
Analysis Software	Sensoft
Repeatability of measurement of Zernike polynomials ⁽⁸⁾	< λ /300 rms
Rms repeatability of wavefront measurement ⁽⁹⁾	< λ /200 rms
Absolute precision ⁽¹⁰⁾	Depends on the surface quality of the reference optical element. Typically λ /20 - λ /100
Wavelength range (visible camera) ⁽¹¹⁾	0.375-1.1 μ with standard camera
Wavelength range (IR camera) ⁽¹¹⁾	0.4-1.8 μ
Wavelength range (UV camera) ⁽¹¹⁾	0.193-1.1 μ
Tilt measurement accuracy (angle depends on the size of the optical elements)	4 μ rad
Dynamic range of measurement by sub-pupil (tilt and defocus mathematically subtracted), depends on combination of aberrations	$\sim \pm 50 \lambda$
Acquisition speed (uncooled camera)	4 Hz
Processing speed	1-2 Hz (configuration dependent)
Built-in collimator for providing parallel light	Fixed or motorized
Camera for SH ⁽¹²⁾	10-bit uncooled CMOS or 16-bit cooled CCD
Dimensions (with motorized collimator)	9 (H) x 22 (L) x 9 (W) cm.
Power requirement (Fiber optic light source)	120V or 220V, 200VA
Power requirement (stepper motor)	12V. 500ma.
Working temperature	-5 to 50°C (with motorized collimator)

Notes and explanations for the specifications table:

1. See the configurations sheet for the various test setups.
2. These values are for converging optical elements. Diverging optical elements can be tested in combination with a converging lens or mirror. Larger or smaller focal ratios can be tested using a different optical setup.
3. With the appropriate auxiliary optics, optical elements of almost any diameter can be tested.
4. Lenslets with different diameters available on request.
5. Lenslets with different focal lengths available on request.
6. With the standard CMOS camera that has a chip size of $6.8 \times 8.5\text{mm}^2$. Pixel size: 6.7μ .
7. Depends on the chip size of the camera. In Optino the camera is mounted externally, and can be changed easily. For details, see separate section.
8. Repeatability of measurement obtained by combining 100 SH frames taken in succession. The error of this coefficient depends on the sampling used for obtaining the SH frame.
9. Repeatability of measurement obtained by combining 100 SH frames taken in succession.
10. This will determine the final accuracy of the measurements, as the SH test is a differential test.
11. Other cameras with an extended range can be used.
12. Cooled camera may be needed in situations where a low reflectivity from the optical surface may require exposure times longer than 100ms.

Dimensions of Optino and BE60



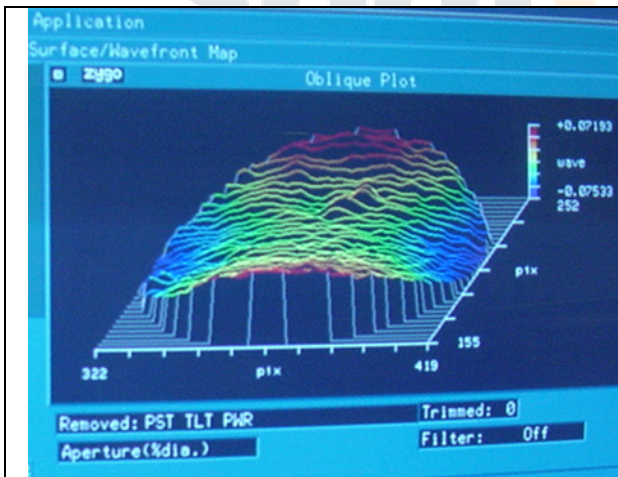
Optino Pro vs. Zygo GPI xp HR Interferometer: A comparison

A small area (7mm) of a hard-disk platter was tested using the Zygo GPI xp HR interferometer and the Shack-Hartmann tester Optino made by Spot-optics s.r.l. The picture below is the flat surface that was tested (shown by the white circle).

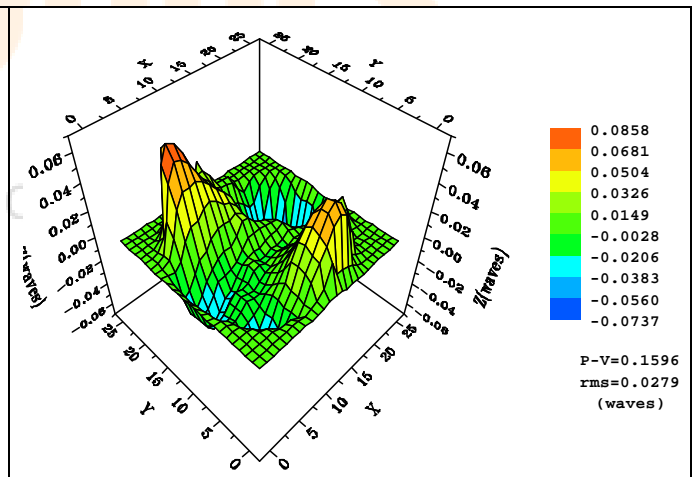
The results obtained with the two instruments are shown in the table at right; the wavelength used for the measurement was 632 nm.



	Zygo GPI xp HR	OptinoPro	Difference
P-V (nm)	93.2	100.2	7
P-V (waves)	0.1473	0.1596	0.011
Rms (nm)	18.3	20.3	2
Defocus (nm)	-23.2	-19.9	-3.3



The 3D surface plot after removal of Tilt, Piston and Power (defocus) obtained with the Zygo interferometer



The 3D surface plot obtained with Optino (after removal of tilt and defocus). There is a good correspondence with the figure at left

Conclusions: Optino, based on the Shack-Hartmann principle, gives results which are in excellent agreement with those obtained from the Zygo interferometer.

About the firm

Spot-optics was founded in 1996. We offer high-technology complete solutions in the field of optics and software, covering any phase from the design of optics and software analysis to the fully developed end-user product.

We have about two decades experience in the field of optical design and software analysis and development. Our software specialization is in the development of software for image processing as well as industrial process control.

Our main product is a wavefront sensor based on the Shack-Hartmann principle. Our Shack-Hartmann wavefront sensors give the optical quality of a large sample of different optical surfaces: from the astronomical telescopes with diameters of several meters, to the DVD lenses with diameter of a few millimeters, to the human eye.

The use of our instruments is made very simple because of the advanced compact optical design and the degree of automation. The control software specifically developed by us allow the full control of the instrument, and our Shack-Hartmann analysis software gives you very precise indications about the quality of the optical element under test. Finally a detailed diagnostics suggests how the optical quality can be improved. All the results from the software are available in a few seconds.

Our first Shack-Hartmann sensor was developed for the test of mirrors of astronomical telescopes. Our Shack-Hartmann wavefront sensor for astronomy Puntino is now operative on several telescopes in Italy, Spain, India and USA. We also offer and have been requested for consultancy for the alignment and quality control of telescopes, and thus Puntino has been also mounted on several additional telescopes in Europe, Africa and USA.

Optino is the Shack-Hartmann wavefront sensor designed and optimized for the optical test in the laboratory and in the manufacturing environment. It is in regular use in production at VDO-Siemens in Germany.

Laserino is the wavefront sensor designed and optimized for testing lasers.

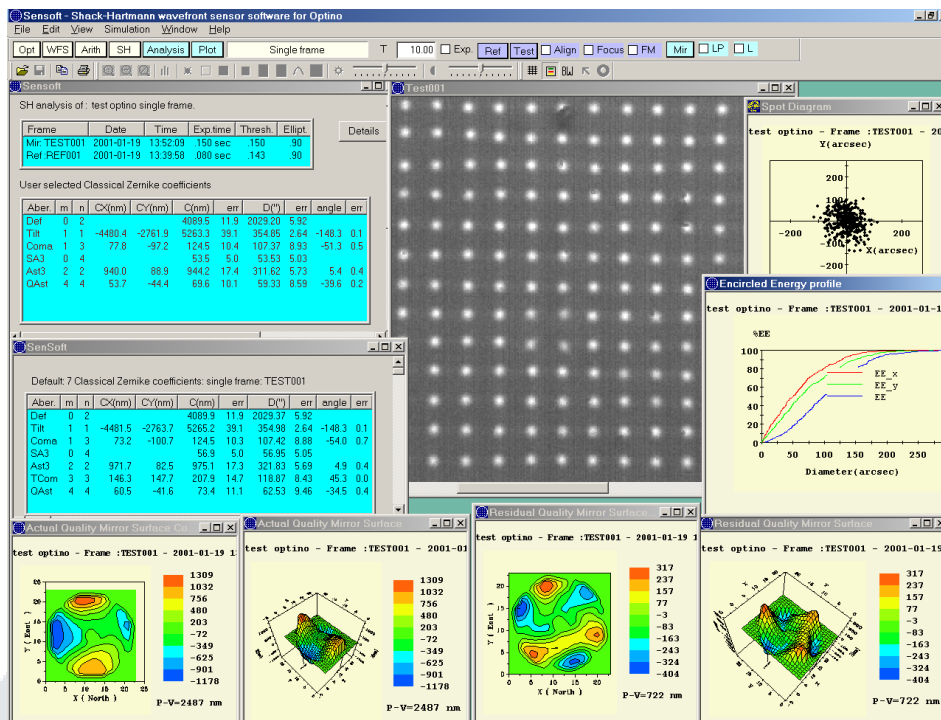
Lentino is the wavefront sensor designed and optimized for testing aspherical lenses with diameter up to 20mm.

We have developed further products in the field of optical alignment and in the medical field.

For further details on our products, we address you to our

Web site: www.spotoptics.com

We can be contacted at the
email: contact@spot-optics.com



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