Accuracy of SpotOptics wavefront sensors

June 2010

Version 4.0

1 Basic concepts: accuracy, precision and repeatability

- Repeatability is not the same as accuracy
- *You can have high repeatability but low accuracy*
- Very often the quoted precision (for example λ/100) is confused with accuracy
- To get high accuracy, you require an elaborate calibration procedure
- For example, to get λ/100 accuracy in double pass, the master flat mirror used for calibration should have that accuracy
- To master calibration mirror itself requires a long procedure of calibration that also takes into account the effect of gravity
- SpotOptics follows a rigorous procedure for calibration

Comparison with Zygo interferometer

- A small area (7mm) of a hard-disk platter was tested using the *Zygo GPI xp HR (high resolution)* interferometer
- The same area was tested with our standard instrument Optino/Sensoft.

Both the tests were done in double pass. A high quality λ/20 flat mirror was used for the calibration.

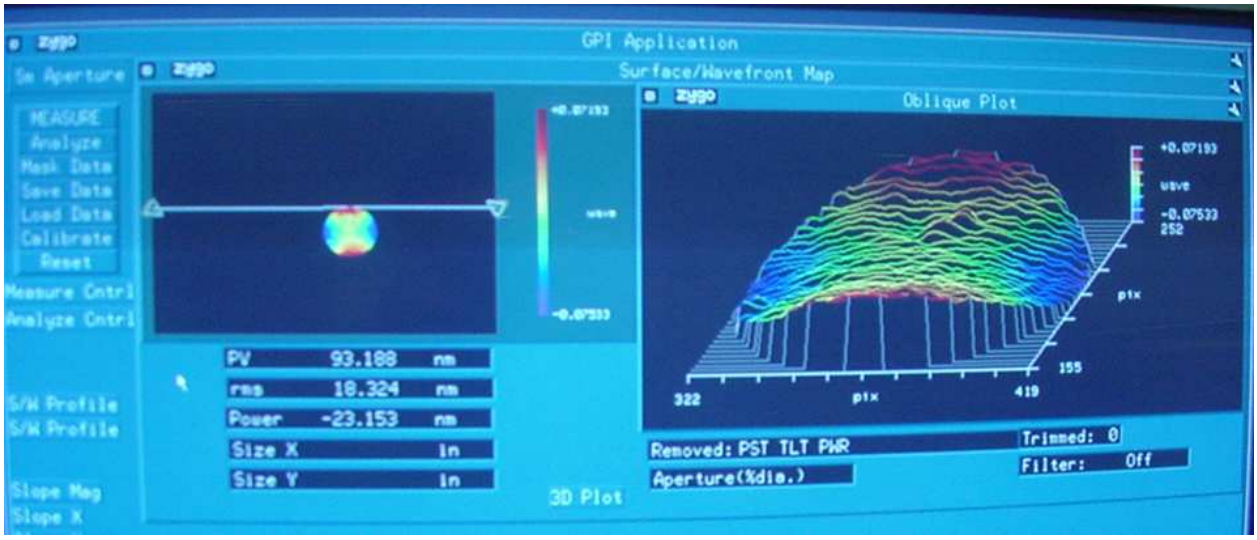
Measured parameters

Parameter	Zygo GPIxp HR	Optino Pro	Difference
P-V (nm)	**93.2**	**100.2**	**7**
Rms (nm)	**18.3**	**20.3**	**2**
Defocus (nm)	**-23.2**	**-19.9**	**-3.3**
P-V (waves)	**0.1473**	**0.1596**	**0.011**

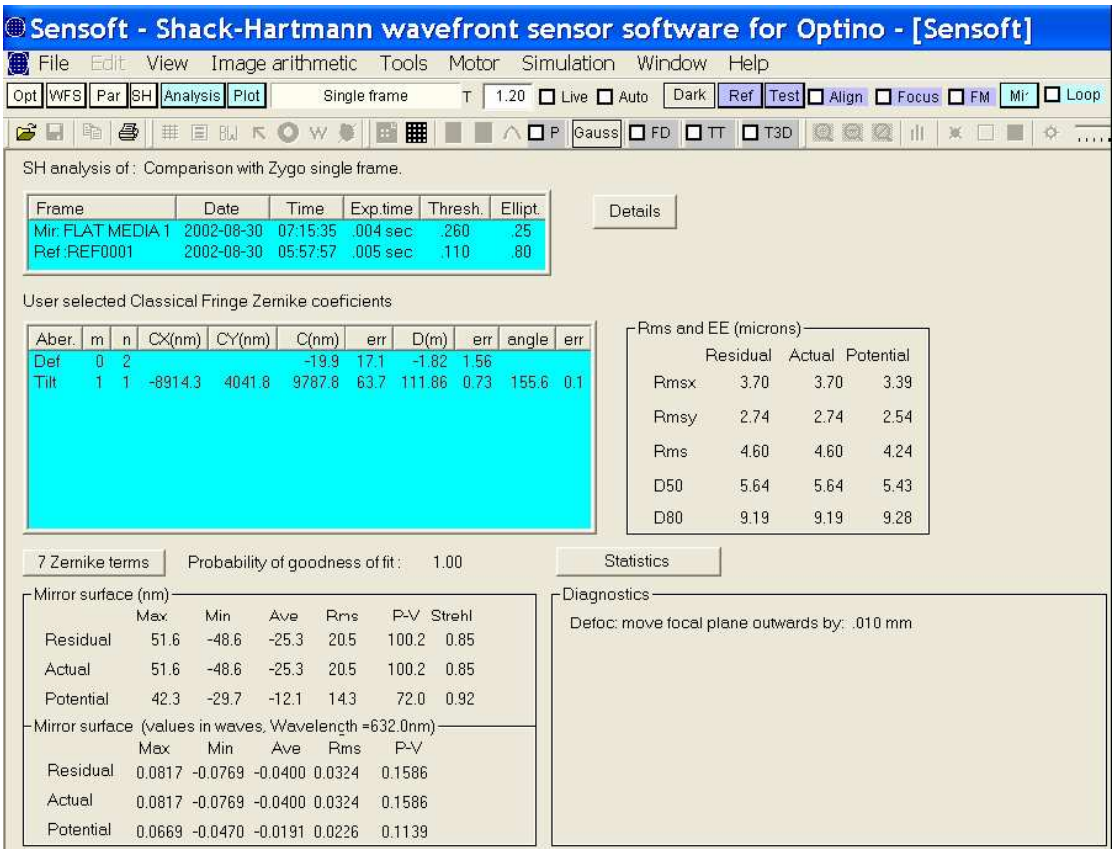
Measurement wavelength: 632.8 nm

Conclusions: The instrument Optino, bases on the Shack-Hartmann principle, gives results that are in excellent agreement with those obtained from the Zygo interferometer.

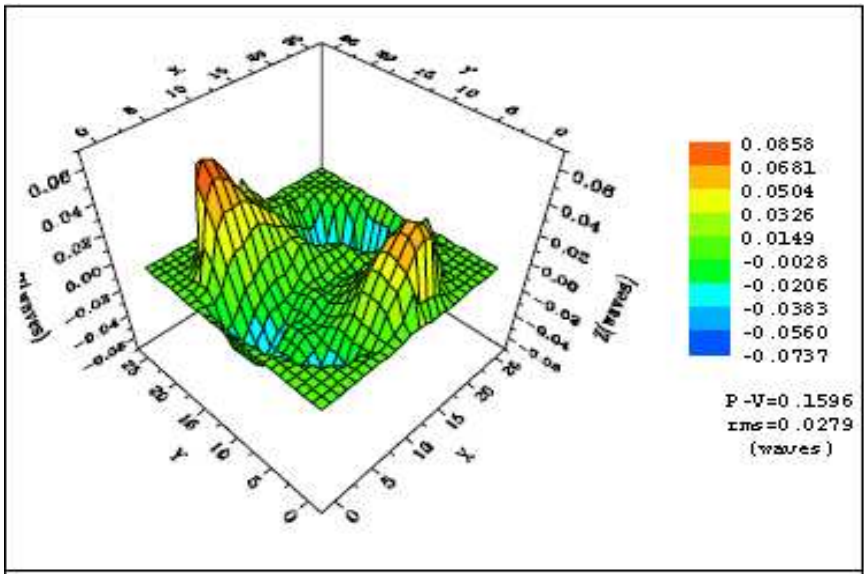
1.1 Screen shot of output from Zygo

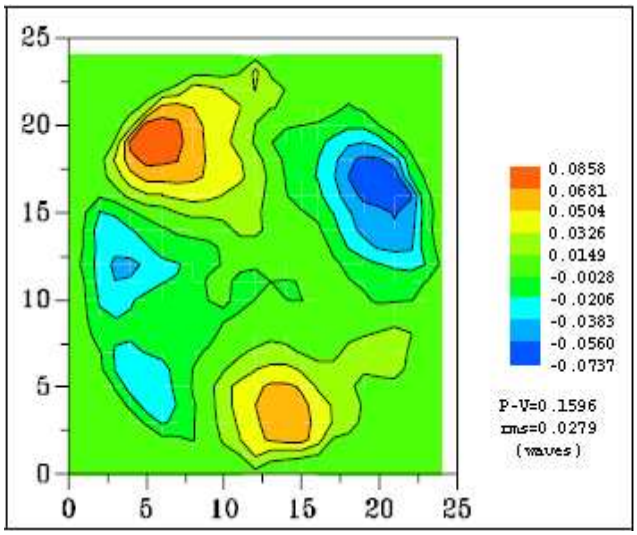


1.2 Screen shot of output from Sensoft



1.3 Surface plots from Sensoft



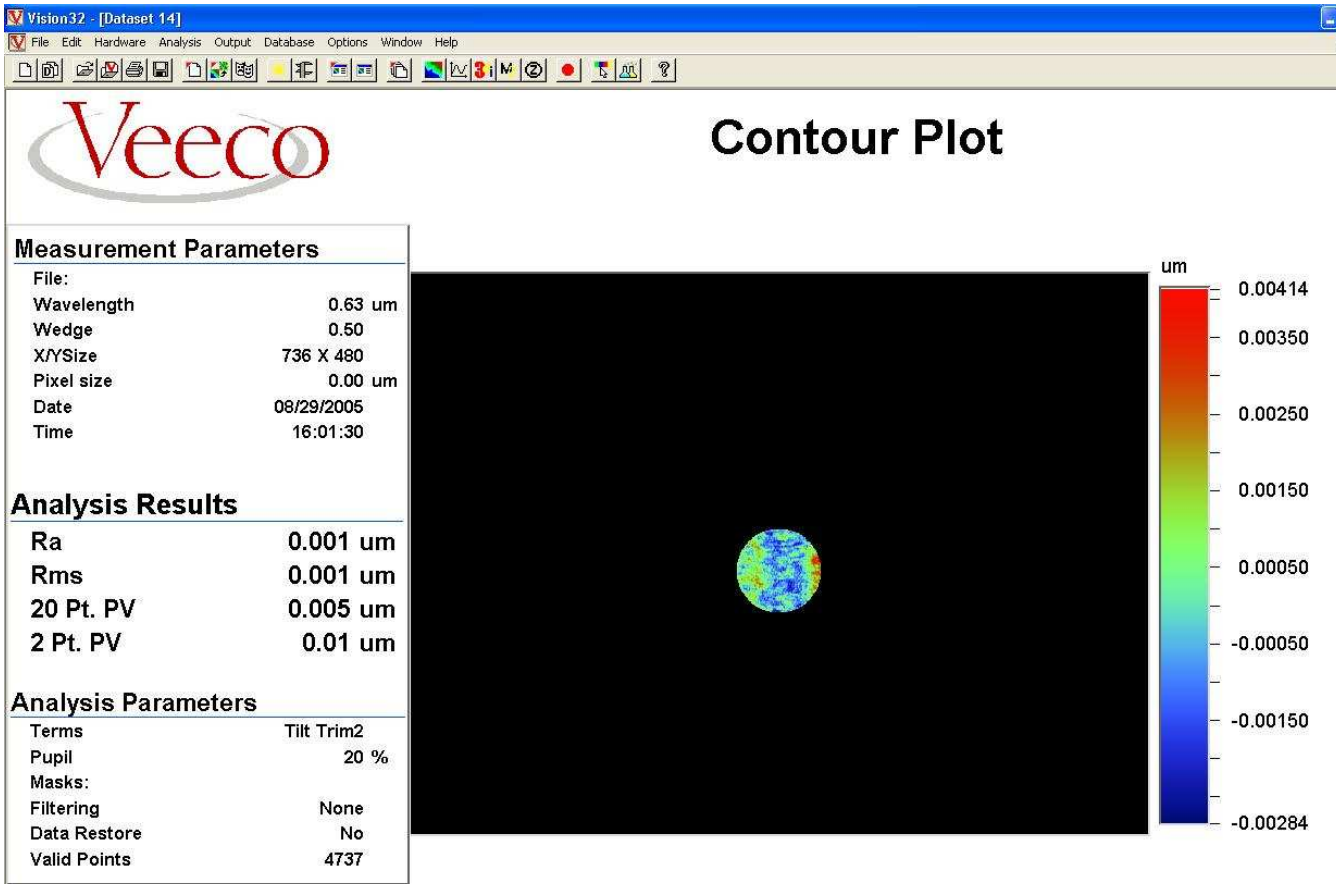


The 3D and contour plot shows the presence of astigmatism both for Zygo and for Optino. The contour plot shows the good agreement between Zygo and Optino.

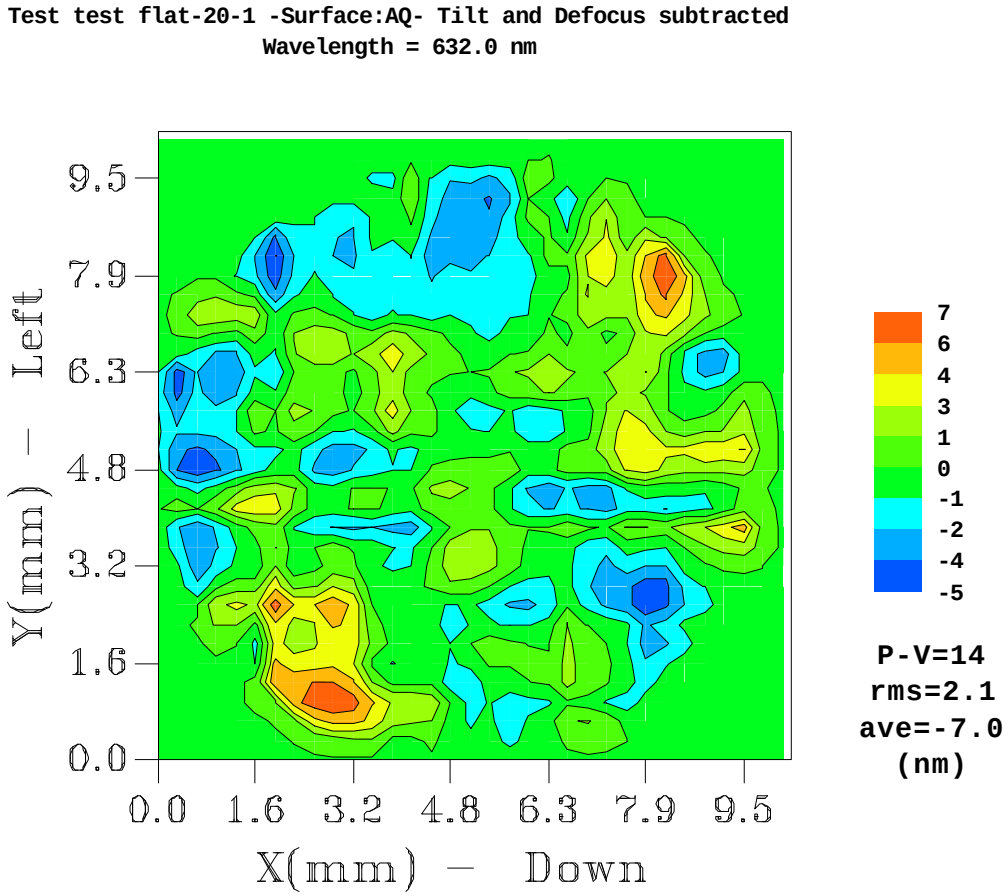
2. Comparison with Veeco interferometer

- An area of 9mm of a high-quality flat mirror was tested using a high resolution Veeco interferometer
- The same area was tested with our standard instrument Optino/Sensoft using a cooled CCD camera

2.1 Screen shot from Veeco Interferometer

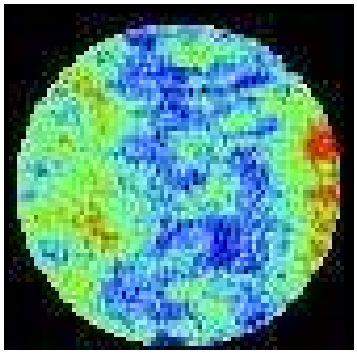


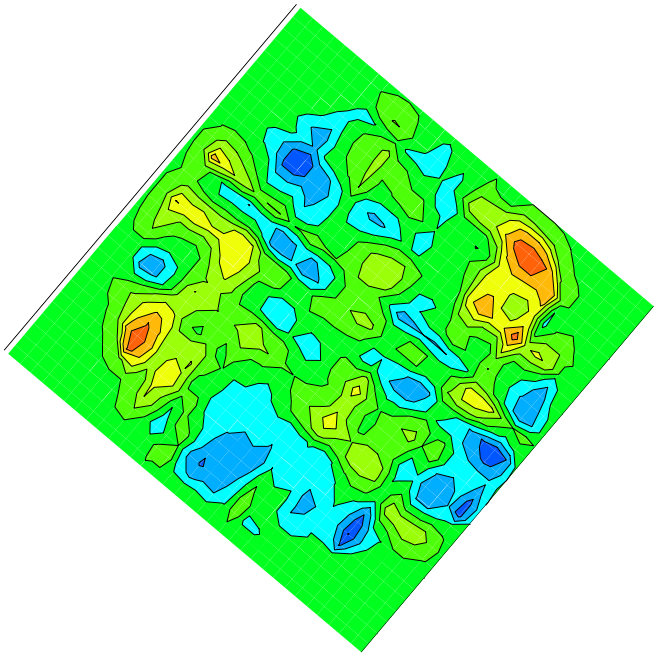
2.2 Screen shot from Optino



The rms accuracy is 2nm rms (better than $\lambda/300$)

2.4 Detailed comparison of wavefront between the Veeco and Optino





The enlarged wavefront from Veeco (on left) and the wavefront as measured by Sensoft (right). A clear correspondence between the two is seen. Some of them have been indicated above

3. Testing an F/3 lens: comparison with Fisba interferometer

- A fast F/3 lens was tested with a Fisba interferometer
- The same lens was tested with Puntino/Sensoft
- The diameter of the lens is 43.2mm

Measured parameters

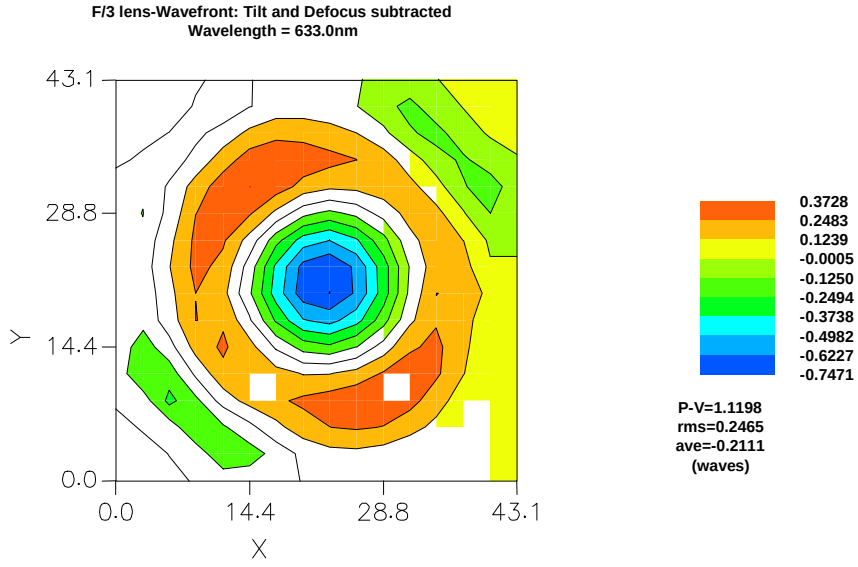
Parameter	Fisba	Puntino	Difference
P-V (Waves)	**1.120**	**1.248**	**0.128**
Rms (nm)	**0.246**	**0.262**	**0.0162**

Measurement wavelength: 632.8 nm

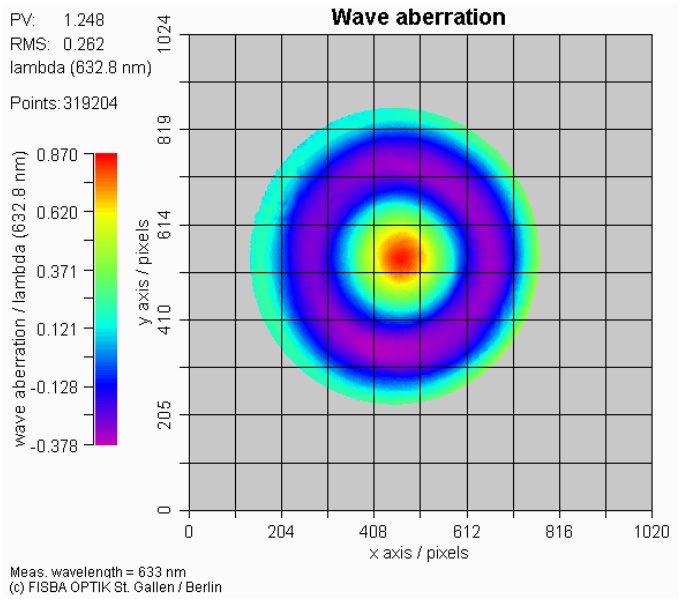
Conclusions:

1. The instrument Optino, bases on the Shack-Hartmann principle, gives results, which are in good agreement with those obtained from the Fisba interferometer.
2. The difference is due to the fact that the lens was not mounted in an identical way for the two instruments

3.1 Wavefront as measured by Sensoft



3.2 Wavefront as measured by Fisba



It is almost the same as that for Sensoft. Note that the sign convention for Fisba is opposite to that of Sensoft

4. Conclusions: as good as interferometry

- Wavefront sensors from SpotOptics give results as good as those from interferometers ***at much lower cost***
- The number of test configurations are much greater in our wavefront sensors compared to interferometers
- This allows a vast variety of optical elements to be tested
- It is important to test the WF accuracy against an independent method of measurement. We have done this against an interferometer. ***This is the real measure of accuracy***
- It is also important to note that SpotOptics removes the effect of the WFS elements (lenslet array and camera) through the reference image. So unlike other wavefront sensor manufacturers, we do not need factory calibration and the client has the full flexibility