Lens system inspection with HASO R-Flex

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APPLICATION NOTE

Introduction

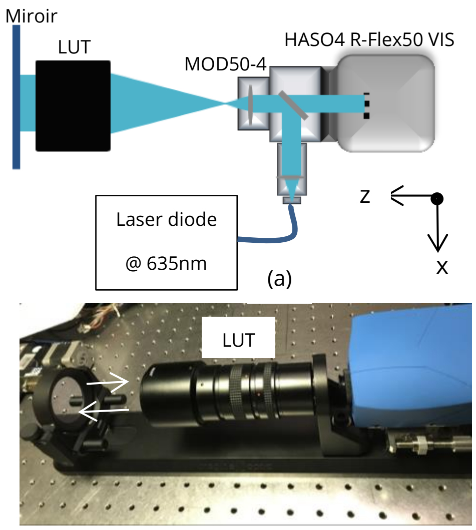
During the development of an optical system, it is necessary to characterize aberration of single components as well as complete systems. The classical technique for evaluating optical components is interferometry. An interferometer gives interference fringes of a reference and the test beam when the sample under test is present. This technique relies on the perfection of the reference beam, which is very sensitive to vibration. Alternative technique is **Shack-Hartmann (SH) wavefront sensing,** a real-time compact and robust optical metrology tool for measuring the aberrations (imperfections) present in a light beam. The SH detection technique is well known for its high accuracy, rapidity, less sensitive to vibrations compared to interferometers. The sensor is constructed with a microlens array in front of a CCD camera. Light computation is required to derive the wavefront shape from local slopes calculated from the displacement of focal spots.

By combining the SH wavefront sensor with a light source, one can guide the light to pass or reflect at the optics under interest and detect the modified wavefront. Imagine Optic pioneered a compact metrology tool, called HASO R-Flex which is based on the SH sensing technique, to facilitate the characterization of optical components or systems and alignment of a telescope. The inspecting beam can be either a collimated or divergent beam. Furthermore, the inspecting wavelength is not limited to 632.8 nm but it can be the wavelengths that the optics will be used. As a result, achromatic aberration can also be measure by injecting different wavelengths to HASO R-Flex through a FC/PC fiber connector.

This application note presents how an optical system, such as a camera lens, can be easily characterized using HASO R-Flex for on-axis and off-axis wavefront aberration and modulation transfer function (MTF).

Optical setup

Wavefront errors of a transmissive optics can be measured by passing the light through and detected the difference of wavefront between with and without the optics. Depending on the design of the optics, a divergent input beam that corresponds to the numerical aperture would be necessary in order to give precise characterization results as well as for comparing with the simulation. The main instruments for the wavefront error measurements are 1) a light source at the wavelength that the optical components will be used, 2) some lenses to form a collimated beam or divergent testing beam, and 3) a wavefront sensor. Alternatively, a metrology tool that is designed for this purpose, such as HASO R-Flex – see Figure 1 (a), could save significant amount of time and give reliable measurement results.



(b)

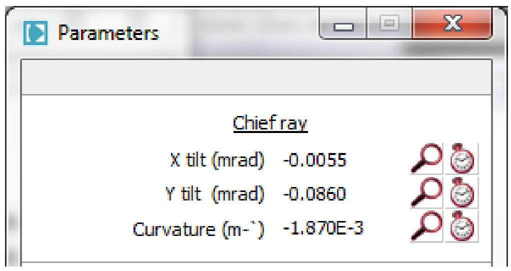
Figure 1 (a) Schematic of the optical setup with HASO4 R-Flex50, objective module MOD50-4, lens under test (LUT) and a plane mirror, (b) a photograph of the setup for the camera lens test using auto-collimation.

We conducted an experiment with HASO4 R-Flex50, so-called HASO R-Flex below, to measure on- and off-axis wavefront errors of a camera zoom lens, LUT in Figure 1 (b), and the Modulation Transfer Function (MTF) at diaphragm size. The laser diode light at 635nm is injected to the HASO4 R-Flex50 via a FC/PC fiber connector. An objective module MOD50-4, a standard module which is sophisticatedly designed for low intrinsic wavefront error and parasitic light was attached to the front of the HASO4 R-Flex50 with a C-mount to give the output divergent beam of F/4.

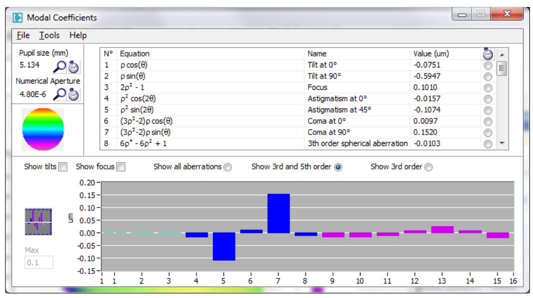
Before placing an optical component of interest, it is necessary to take a reference wavefront, which records the wavefront errors of the HASO R-Flex and the objective module. This can be done by inserting a spherical mirror in front of the objective module and get the auto-collimation of the light to the wavefront sensor. This systematic wavefront error shall be subtracted from the wavefront of the optics under test. After taking the reference wavefront, the camera lens then was placed in front of the objective module and followed by a reflecting flat mirror.

Optical alignment

The principle of this measurement system is based on auto-collimation. To facilitate the alignment, the HASO R-Flex was mounted on a translation-rotation stage. This allows the translation along xyz directions and the rotation about the x and z axes. The LUT was fixed and the reflecting mirror was mounted on a tip/tilt stage. This configuration can be applied to an optical system with large dimension such as a telescope.



(a)



(b)

Figure 2 Parameters in WaveView to help optical alignment.

In order to get the auto-collimation, the curvature seen by the wavefront sensor should be minimum, as well as x- and y-tilts. These parameters displayed in Chief ray session in the WaveView metrology software, see Figure 2 (a). Low order aberrations should be minimized real time for the on-axis configuration with the help of Modal coefficient display as shown in Figure 2 (b).

Measurement results

This section presents off-axis wavefront characterization result and the MTF as a function of the zoom lens pupil size.

On-axis and Off-axis

A lens collects light from a point on an object and focuses it to a corresponding conjugate point on an image. The inability of a lens to form a diffraction-limited image is caused by lens aberrations such as astigmatism, coma and spherical aberration. Using the optical setup explained previously, HASO R-Flex can analyze the off-axis aberration by the translation stage underneath. Figure 3 shows the on- and off-axis configurations. The flat mirror placed after the LUT has to be rotated in order to collect the light back to the wavefront sensor when translating the HASO R-Flex.

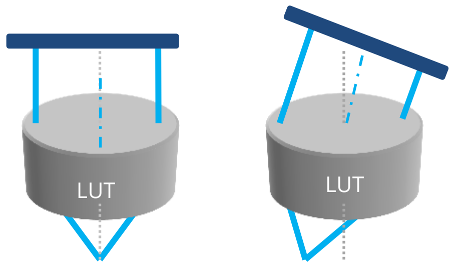


Figure 3 Schematic of on- and off-axis measurements.

The HASO R-Flex was translated along the x-axis and the corresponding wavefronts were recorded, Figure 4. Five Zernike coefficients which typically affect the image quality are plotted in Figure 5. From these two figures, we can see that coma at 0° significantly depends on the off-axis position. Other aberrations are slightly changed.

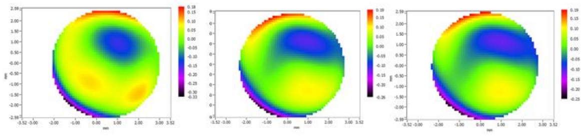


Figure 4 Wavefronts of the off-axis (a) and (c); and on-axis positions (b). The wavefront errors are 79, 72 and 70 nm RMS, from left to right.

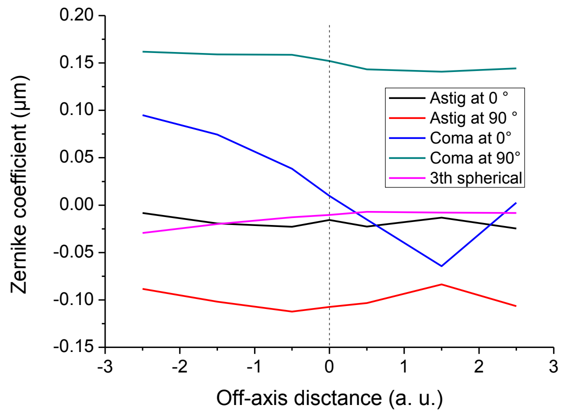


Figure 5 Zernike coefficients at different off-axis positions.

MTF

The modulation transfer function in particular is a classic criterion for the characterization of optical systems, and is often used to judge the quality of an optical system in terms of its spatial frequency response, particularly for imaging systems. Here we present the operation of the MTF calculation software using the data from the wavefront measurement performed by a HASO-type sensor operating on the Shack-Hartmann principle, Figure 6.

In this experiment, the system was set at the on-axis configuration. The diaphragm of the zoom lens was reduced manually and the evolution of contrast from the MTF data was recorded. From **Figure 7** we can see that reducing the diagraph increasing MTF contrast. The maximum contrast is found around 40% of the full pupil. When the pupil was reduced further, the contrast rapidly decreased.

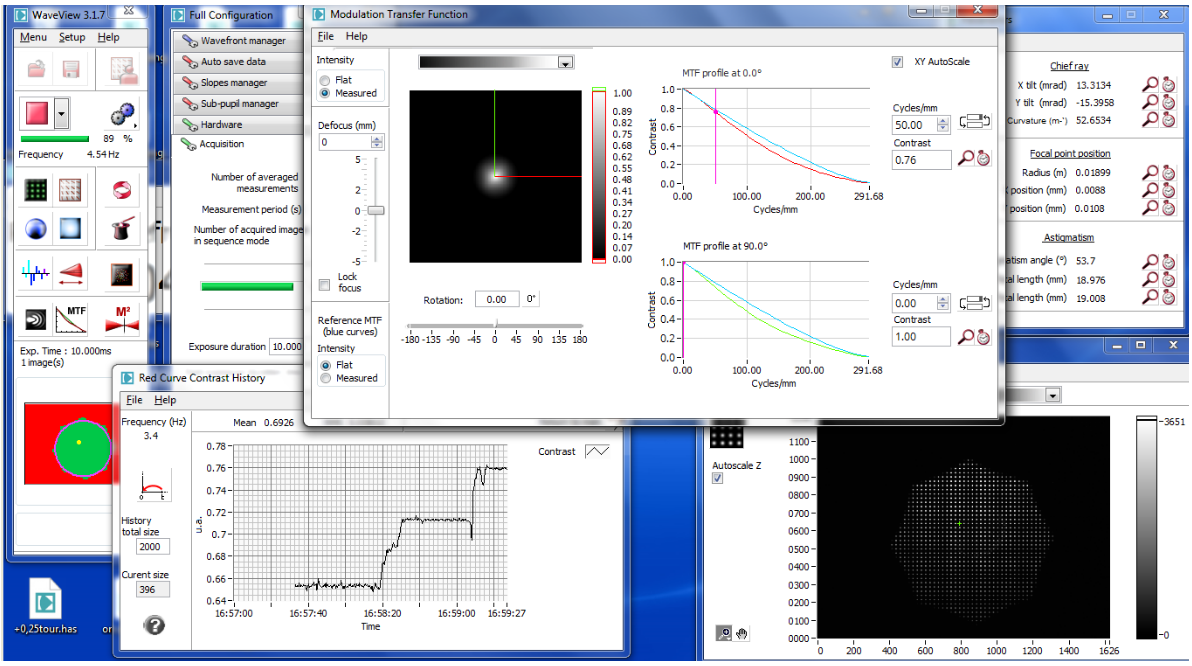


Figure 6 Screen shot of the MTF measurement.

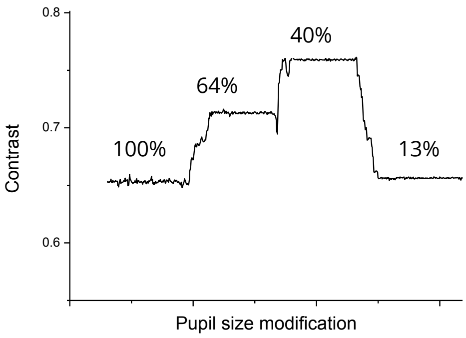


Figure 7 Change of the MTF contrast as a function of diaphragm aperture in percent.

How to choose objective module for HASO R-Flex

There are two F-numbers involved when using an output divergent beam; F-number of objective module (FOM) and F-number of the optics under test (FOT).

- FOM=FOT: optimal case – the full pupil of the wavefront sensor is used.
- FOM<FOT: possible case – the sampling beam is smaller than the wavefront sensor pupil. For example MOD50-6 can be used for the optics with F/8.4.
- FOM>FOT: not recommend – part of the optical component under test is not seen by the wavefront sensor

Summary

HASO R-Flex was used for charactering a camera zoom lens to quantify the aberrations both on- and off-axis. The MTF contrast was observed as a function of pupil size. A guide to select the right objective module is proviced.
Another important feature of HASO4 R-Flex50 is the detection of achromatic aberrations, which can be conducted by changing the inspecting light source wavelength.