Adaptive optical system based on 37-channel piezoelectric deformable mirror: technical data

OKO Technologies,

OKO Technologies is the trade name of Flexible Optical BV

1 Installation of FrontSurfer software

1. Start “setup.exe” from “fsurfer” directory of the installation CD to install FrontSurfer to your computer. Follow further installation instructions.
2. Start “setup.exe” from “sentinel” directory of the installation CD to install drivers for the protection dongle. During the installation, make sure that both “Parallel system driver” and “USB system driver” are options are enabled.
3. To be able to operate with deformable mirrors, you need to install “DLPortIO” library. Go to the directory “DLPortIO” and run the setup program “port95nt.exe”. It will install the library. Restart your computer when the installation is complete.
4. Go to the directory “basler”. Run the setup program and install drivers and applications for Basler A601f camera. Attach the camera to a Firewire port of your computer only when the program will request it. Please note that 12 V DC voltage should be supplied to the camera via the Firewire port. When using a notebook, you should connect an external adaptor to “+12 V” connector on the Firewire interface card.
5. Start “BCAM Viewer” and make sure that you can see the image from camera.
6. Connect DAC40USB unit to a USB port of your computer. Drivers for this unit can be found in “DAC40USB/Driver” directory of the installation CD. Install the drivers. Start “DAC40USB/Program_win2000/TEST_DAC40.exe” to make sure that the unit is recognized by the system.
7. Attach the FrontSurfer dongle to a free USB port. The system will recognize the device and install the corresponding drivers.
8. Run “FrontSurfer” from the start menu. Load wavefront sensor calibration data. For this purpose go to the menu “Options ⇒ Parameters”. In the dialog box “Sensor parameters” press “Load” button and load the calibration file from the CD “fsurfer” directory. ”calibration_mask91.txt” is the calibration file for the Hartmann mask with 91 subapertures; “calibration_mla127.txt” is for the microlens array, which is already attached to the camera.
9. Set frame grabber type for FrontSurfer. For this purpose go to the menu “Options ⇒ Parameters”. In the dialog box “Camera interface” check “Plugin” option. After that, load plugin for the Basler camera by pressing “Load” button and selecting “BCAM1_8.dll” file in the FrontSurfer installation directory. Press “OK”.
10. Set camera viewer type through the menu command “Preview ⇒ Configuration”. Select the option “internal viewer” and press “OK”.
11. Load configuration of channels for the deformable mirror. With this purpose go to the menu command “Mirror ⇒ Configuration”. In the dialog box “Deformable mirror configuration” press the “Load” button and load the file “piezo37_2005usb.txt” from the CD “fsurfer” directory. In the same dialog box, correct the serial number of the USB unit. The serial number is written on a label attached to the unit’s cover.

Installation is done. See FrontSurfer manual for more information.

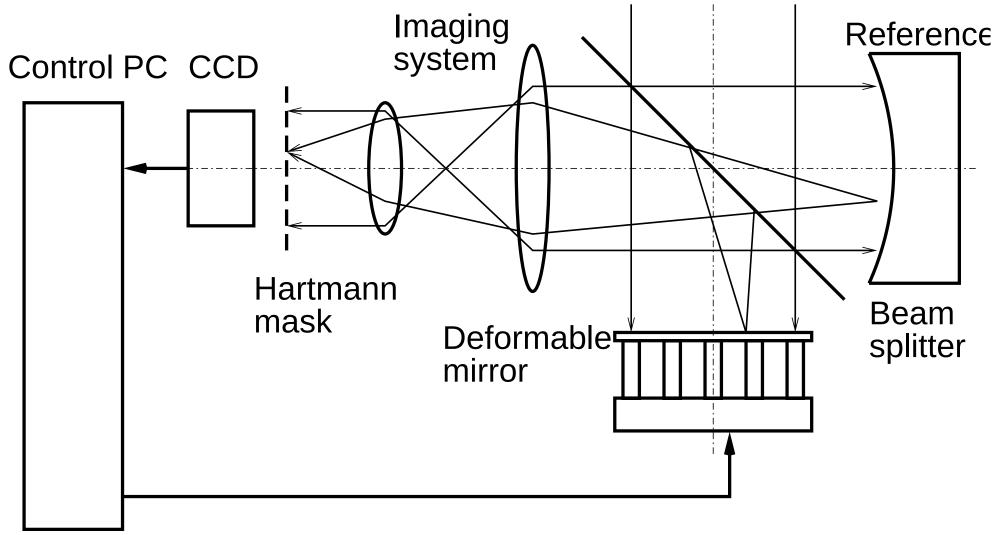

Figure 1: Scheme of typical adaptive optics setup.

2 Assembling and running of adaptive optical system

1. Place the mirror and the wavefront sensor into an optical setup. The optical scheme should satisfy the following conditions.

   a) The optics should re-image the plane of the mirror to the plane of the Hartmann mask (or microlens array).

   b) The scheme should scale the beam in such a way that the working area of the mirror (about 25 mm) should be re-imaged to the working area of the Hartmann mask/microlens array (4 mm).

   c) The optics should allow for calibration. In the general case, it consists of separate measurement of the complete setup aberration with ideal object or a source of ideal wavefront, replacing the one to be tested.

   The typical setup for functional feedback loop is shown in the Figure 1. Flat mirror can be used as a reference.

2. Connect the Hartmann wavefront sensor to a Firewire port of your computer. Please note that 12 V DC voltage should be supplied to the camera via the Firewire port. When using a notebook, you should connect an external adaptor to "+12 V" connector on the Firewire interface card.

3. Disconnect DAC40USB control unit from your computer. In order to provide ground to the mirror and connect it to the ground of the amplifier board, jumper JP2 of the unit should be set to the position 2-3.

4. Connect the amplifier unit to DAC40USB unit using two 20 pins-to-26 pins cables.

5. Connect the mirror to the amplifier unit using two 20 pins-to-20 pins cables. Fix the cables to the optical table.

6. Connect DAC40USB to the computer using a USB cable.

7. Start FrontSurfer. Turn on the preview mode in FrontSurfer and check an image from the Hartmann sensor for both the calibration beam and those reflected from the mirror. It is highly desirable to provide that no spots are missing.

8. Turn on the high-voltage amplifier unit. In FrontSurfer go to the menu command "Mirror → Set values". Now you may start to use the mirror by applying different control voltages to the actuators. See FrontSurfer manual for instructions on using of the feedback loop operation mode.

3 Microlens array

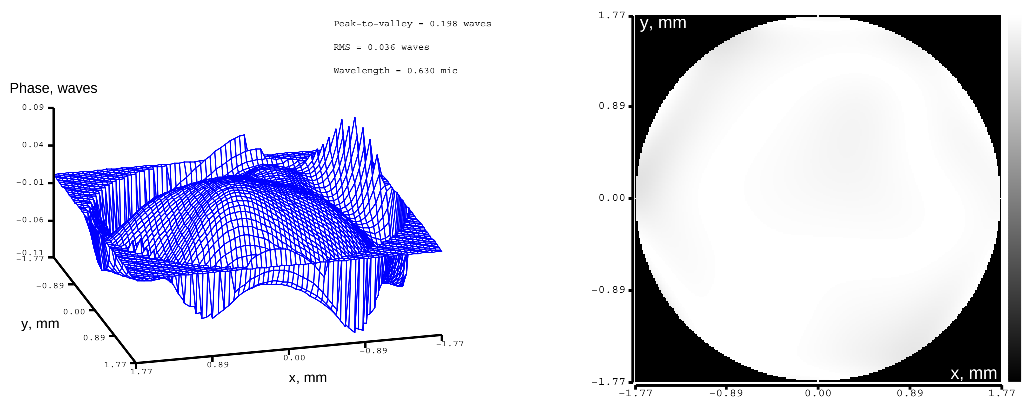

Figure 2: Wavefront sensor error due to irregularity of the microlens array; wavelength 0.63 μm.

The wavefront sensor is supplied with a microlens array having hexagonal arrangement of 127 microlenses; the sensor is calibrated. The measured wavefront error of the sensor for the case, when an ideal hexagonal grid is used as a reference, is shown in Figure 2; this error is due to irregularity of the microlens array. When a higher precision is required, it is necessary to make a separate measurement of the reference pattern.

4 Mirror testing

The mirror was calibrated and tested in feedback loop operation mode before shipping. The results of testing are presented below.

FrontSurfer perform wavefront correction in a series of iterations. If the residual aberration ϕ_n at the n-th iteration corresponds to the set of actuator signals $\mathbf{X}_n$ then the actuator signals at the next step $\mathbf{X}_{n+1}$ will be determined by expression

$$\mathbf{X}_{n+1} = \mathbf{X}_n \text{ - } g\mathbf{A}^{-1}\phi_n,$$

where g is the feedback coefficient with value in the range (0..1], $\mathbf{A}$ is the influence matrix of the mirror, $\mathbf{A}^{-1}$ is its pseudo-inverse given by

$$\mathbf{A}^{-1}=\mathbf{V}\mathbf{S}^{-1}\mathbf{U}^T,$$

$\mathbf{U}$, $\mathbf{S}$ and $\mathbf{V}$ are the singular value decomposition (SVD) of $\mathbf{A}$ which is $\mathbf{A}=\mathbf{U}\mathbf{S}\mathbf{V}^T$ [1]. The columns of the matrix $\mathbf{U}$ make up orthonormal set of the mirror deformations (modes), and the values of the diagonal matrix $\mathbf{S}$ represent the gains of these modes. Discarding those modes having small singular values may improve controllability of the system.

Experimental singular values for the piezoelectric deformable mirror are given in Figure 3; SVD modes are shown in Figure 4.

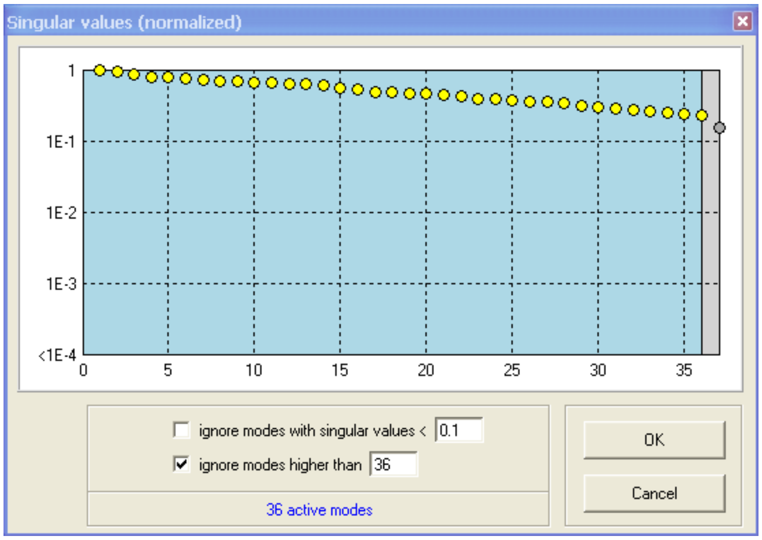

Figure 3: Singular values of the 37-channel piezoelectric mirror.

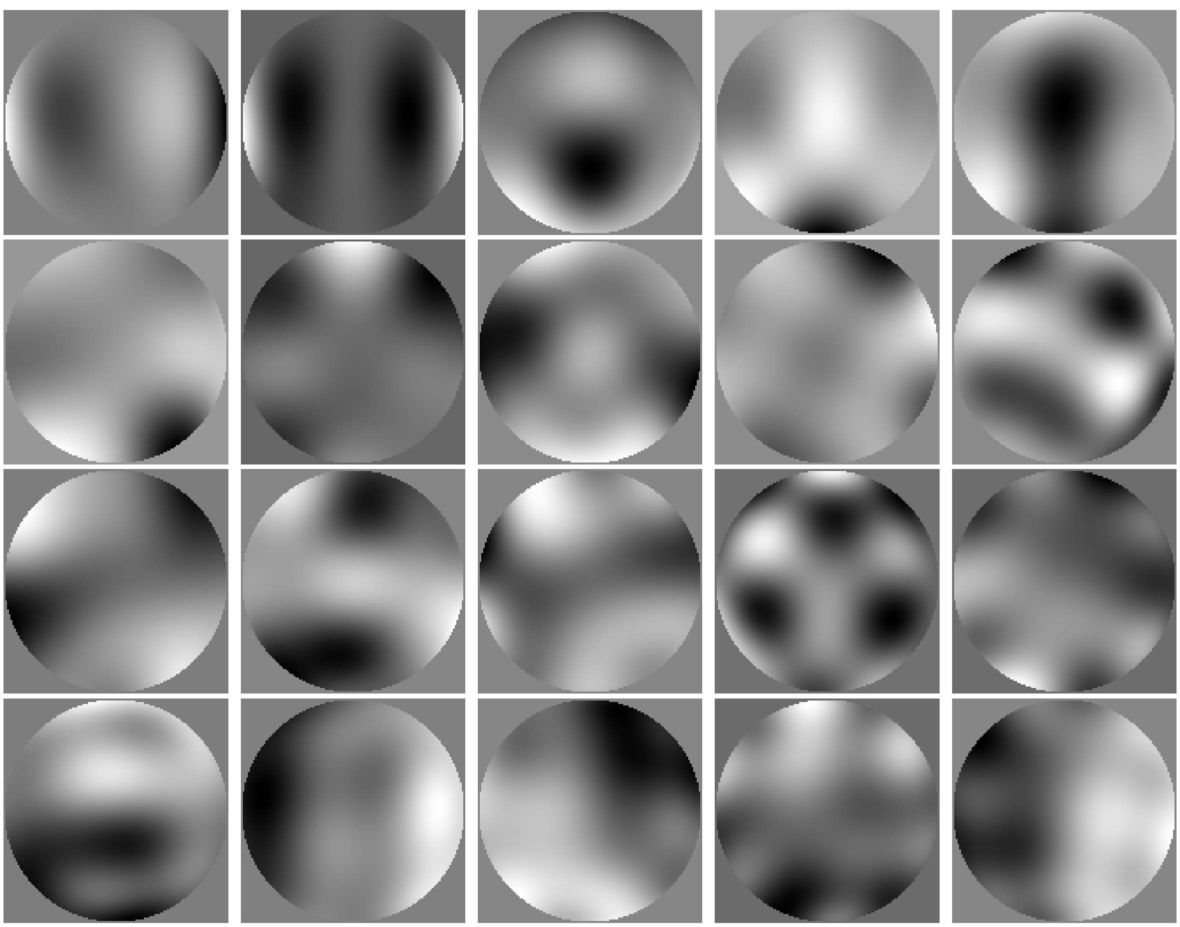

Figure 4: 20 first modes of the 37-channel piezoelectric mirror.

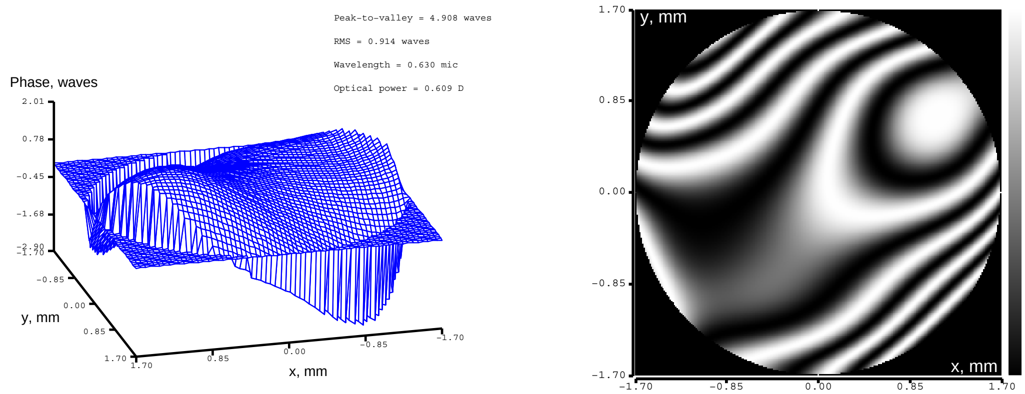

Figure 5: Initial shape of the mirror, which was produced by setting all mirror values to 0, with respect to the reference mirror.

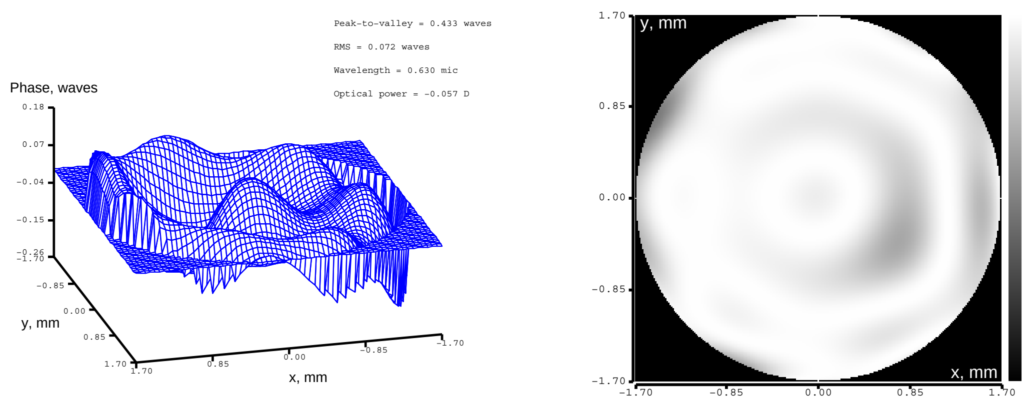

Figure 6: Optimization with respect to the reference mirror; residual aberrations.

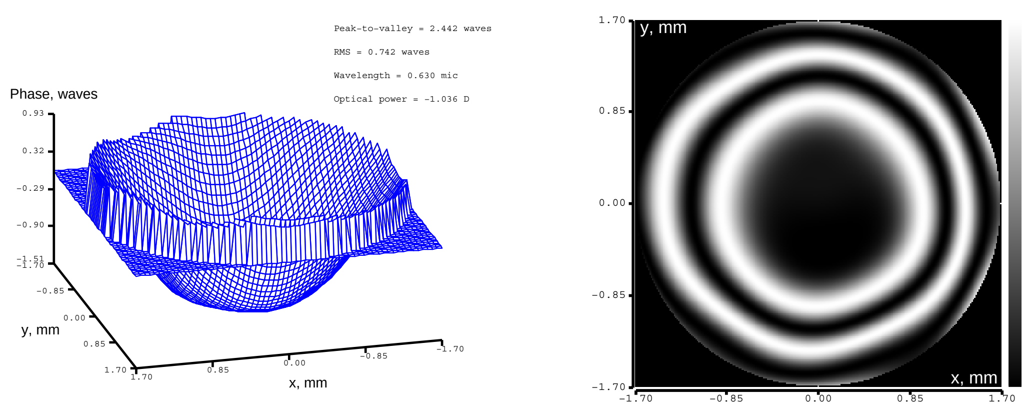

Figure 7: Generated defocus, Zernike term Z[2,0], amplitude 1 μm.

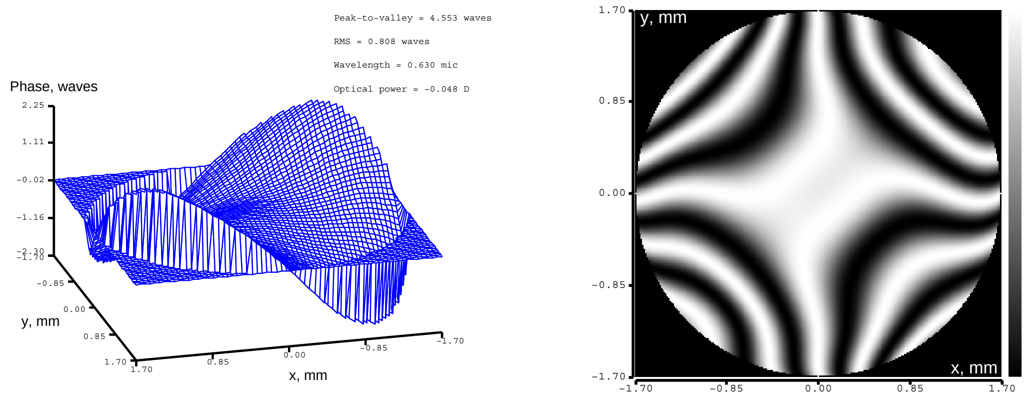

Figure 8: Generated astigmatism, Zernike term Z[2,2], amplitude 2 μm.

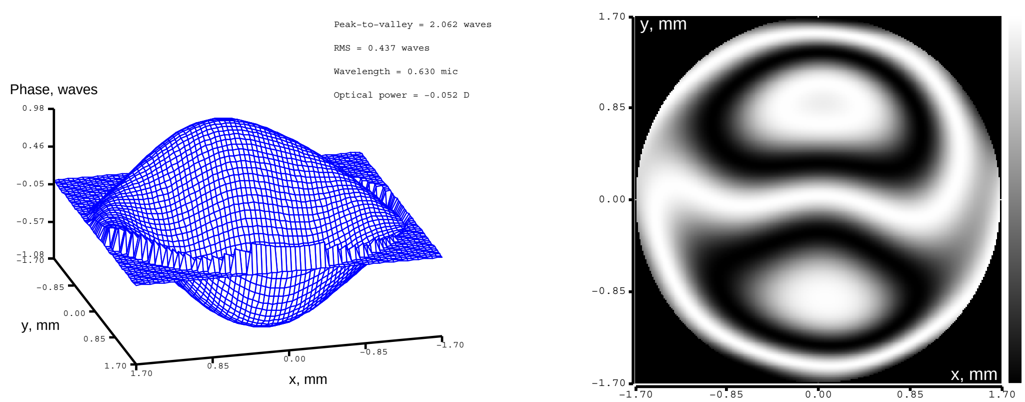

Figure 9: Generated coma aberration, Zernike term Z[3,1], amplitude 1 μm.

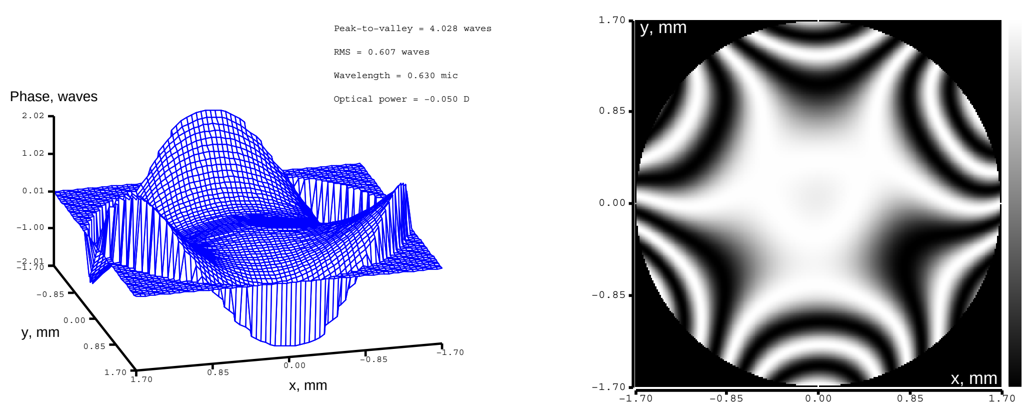

Figure 10: Generated trifoil aberration, Zernike term Z[3,3], amplitude 2 μm.

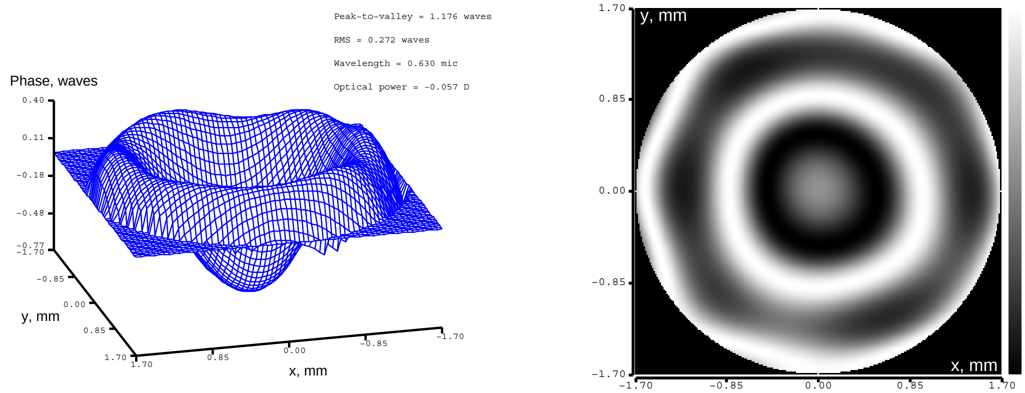

Figure 11: Generated spherical aberration, Zernike term Z[4,0], amplitude 0.5 μm.

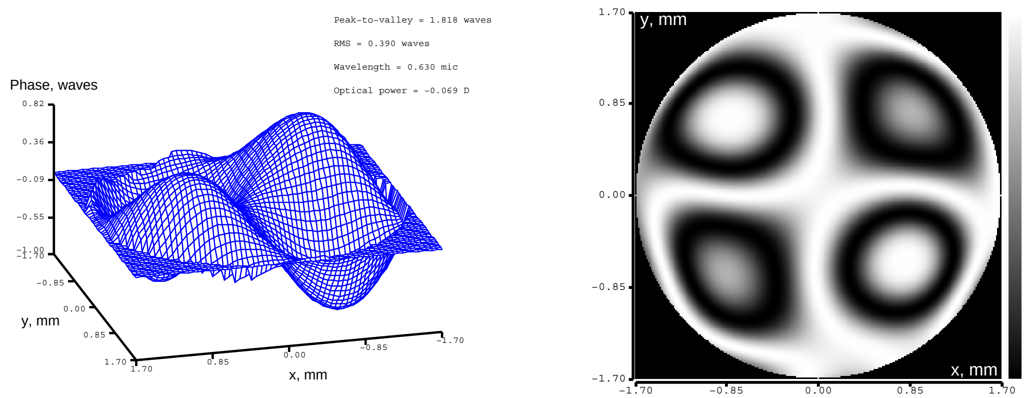

Figure 12: Generated Zernike term Z[4,2], amplitude 1 μm.

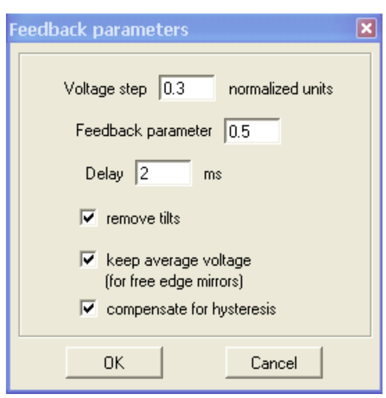

Figure 13: Settings in the "Feedback parameters" dialog box used throughout the tests.

Flat mirror was used as a reference. Optimization started from the initial shape of the mirror, which was produced by setting all mirror values to zero; this shape is shown in Figure 5.

In the first test we optimized shape of the deformable mirror with respect to the reference mirror; residual aberrations are shown in Figure 6. In the following tests we generated various Zernike aberrations in addition to the bias curvature; results are presented in Figures 7-12. Figure 13 shows the settings of the "Feedback parameters" dialog box used throughout the tests.

References

[1] C. Paterson, I. Munro, C. Dainty, A low cost adaptive optics system using a membrane mirror, Optics Express **6**, 175-185 (2000).