# REAL-TIME ADAPTIVE CORRECTION FOR WAVEFRONT ABERRATIONS

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*Received January 12, 1989*

*An adaptive optical system for large-scale wavefront aberration correction is proposed. The designs of a phase-distortion sensor and a controllable flexible mirror are described.*

A number of important applied optics problems are concerned with beam focusing in a turbulent atmosphere. The effect of random refractive-index fluctuations along the laser beam propagation path leads to a change in the luminous flux density at the receiver. To improve the situation and obtain a diffraction-limited beam spot at the target is made possible through the use of adaptive optical tracking systems. High operating speed of this kind of system can be provided by a phase-conjugation algorithm[1] by which real-time measurements of wavefront fluctuations are carried out and the resulting wave surface is approximated by an adaptive corrector. The well-known adaptive systems employ a rotating grating lateral-shear interferometer as a phase analyzer[2,3] and a monolythic bimorph mirror as a corrector[2].

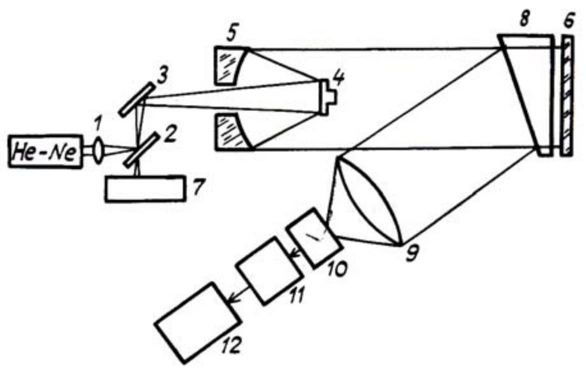


*FIG. 1. Optical scheme: 1 – microscope objective; 2 – split mirror; 3 – tilt corrector; 4 – adaptive mirror; 5 – spherical mirror; 6 – reflector; 7 – wavefront sensor; 8 – wedge-shape splitter; 9 – objective 10 – microscope; 11 – TV-camera; 12 – buffer memory.*

In this paper an adaptive Cassegrinian type device is described wherein a phase-distortion analysis is effected by means of a simpler design of the Hartmann sensor and a semipassive bimorph mirror[4,5] is utilized for phase compensation. An optical block-diagram of the device is shown in Fig. 1.

A laser beam at 628 nm is successively directed onto a microscope objective, a split mirror, and a tilt corrector and enters a Cassegrain telescope formed by a pair of mirrors of adaptive and spherical configuration (1 m FD). The output beam passes through a 6-m model pathlength, is reflected from a plane mirror simulating a distant reflector, and reenters the optical path of the telescope in the return direction. The split mirror couples out the beam onto a wavefront sensor whose electric signals are then analyzed by $D/A$ converter generating corrector control signals. A wedge-shaped beam splitter placed before the plane reflector guides a portion of the light to a recording arm including a 2-m FD objective, a microscope, and a TV camera. The camera output is fed to a buffer memory[6] linked with an Electronika-80 microcomputer. The device makes it possible to register an image in the focal object plane and judge the performance of the adaptive system by the form of the focal spot.

A piezoelectric-ceramic laser beam deflector[7] was used as the tilt corrector. The adaptive mirror served to correct for second-order phase aberrations, such as field curvature (defocusing) and astigmatism. The mirror design is shown in Fig. 2.

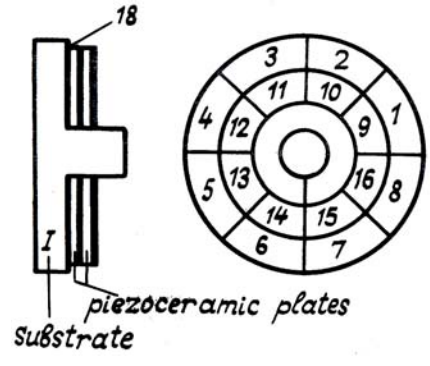


*FIG. 2. Adaptive mirror design substrate; piezoelectric-ceramic plates*

Glued to a mushroom-shaped quartz substrate was a piezoceramic double-disc assembly. Silver electrodes were deposited on both surfaces of each disc. A shared internal electrode was kept at zero potential while control voltages with amplitudes up to 300 V were impressed on the external electrodes. The application of voltage to one of the electrodes (No. 17) caused spherical bending of the mirror surface and enabled us to correct for the curvature of the light beam field. Electrodes 1–8 and 17 served to compensate for residual static aberrations involved in the mirror-making process. External electrode array 9–16 was used for dynamic correction of astigmatic aberrations.

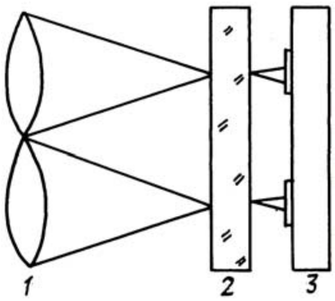


*FIG. 3. Wavefront Hartmann sensor 1 – lens raster; 2 – glass-fiber plate; 3 – photodetector array*

The Hartmann sensor of Fig. 3 measured the intensity of the wavefront aberration experienced by the beam which was received by the telescope. The laser beam passed through a lens raster formed by four 100-mm-FD square lenses that focused the beam onto the surface of a glass-fiber plate. A photodetector array consisting of four multisector photodiodes was located at a distance of 3 mm from the plate. The light intensity in the four sectors of each photodiode yielded two orthogonal components of the focal spot displacement at the corresponding sensor subaperture. The use of the glass-fiber plate provided an increased focal spot size on the light-sensitive surface of the photodiodes and a more uniform light-intensity distribution over the spot.

The sensor electronics generated signals $A$, $B$, $C$, $D$, and $E$ proportional to the distorted beam phase expansion coefficients in the first five Zernike polynomials[8]:

$$\Phi(x,\ y) = Ax + By + C(x^2+y^2) + D(x^2-y^2) + 2Exy$$

The signals arrived at five identical tracking circuits, each having an active low-Q low-pass filter (500 Hz bandwidth) and an electronic integrator. On passing through high-voltage dc amplifiers with an output voltage amplitude of 300 V the signals were directed onto the tilt-corrector and bimorph mirror electrodes.

The results obtained from the adaptive system operating in a model atmosphere are depicted in Fig. 4.

When variable inhomogeneities leading to astigmatic aberrations and defocusing of the laser beam were introduced into the laser path, the light spot at the lens focus (Fig. 1) was of the form illustrated in Fig. 4a. Turning off the phase-correction system feedback dramatically reduced the focal spot size (Fig. 4b). The frequency range spanned by the correction was 350 Hz. The dynamic range of the tilt-correction, defocusing, and astigmatism was 0.5 mrad, 10 μm, and 2 μm, respectively. The experiments made using the proposed system demonstrated the feasibility of its efficient application to the correction of large-scale aberrations induced by atmospheric turbulence.

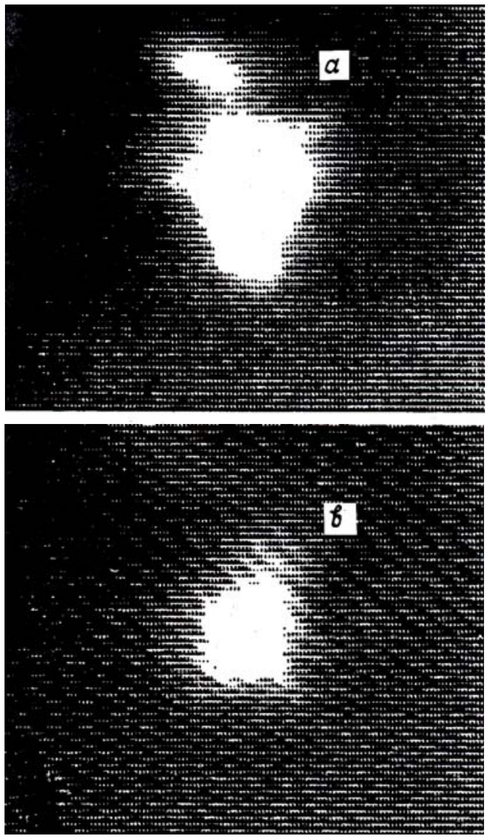


*FIG. 4. Focal* Spot *Image in the Output Objective Plane: a) with feedback open; b) with feedback closed.*

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