

CONTROL OF LASER RADIATION PARAMETERS

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Reduction of wavefront aberrations and laser radiation divergence of the 'Luch' facility with the help of an adaptive system

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***Abstract*. An adaptive system for the compensation of static and thermally induced wavefront aberrations of the amplification path of the 'Luch' laser facility is described. This system provided the reduction of the amplitude A of wavefront aberrations of high-power radiation and the standard deviation σ by a factor of ~ 3: from $A = 9.6$ μm, $\sigma = 2.4$ μm to $A = 3.2$ μm, $\sigma = 0.6$ μm, which decreased the radiation divergence by half.**

Keywords: *neodymium amplifier, adaptive system, wavefront aberrations, radiation divergence.*

In large-scale neodymium-glass laser facilities under construction [1, 2] and in the Luch module [3, 4] of the Iskra-6 facility [5] being designed, a low output beam divergence and high output energy are required to achieve high intensities when focusing the radiation on a target. High-power solid-state laser systems exhibit wavefront aberrations arising from the static and dynamic ('thermal') inhomogeneities of the refractive index in optical elements of the amplification path, which increase the divergence and impair the quality of beam focusing [6, 7]. Static aberrations are primarily caused by the inhomogeneities in the optical materials and the inaccuracy of surface processing of the optical elements (active elements, windows, lenses, mirrors, etc.). Dynamic aberrations commonly arise due to the heating of the optical elements by the pump radiation.

The wavefront aberrations in laser systems can be compensated for by using different adaptive systems [1, 8 – 11], which reduce the radiation divergence to diffraction-limited values. The wavefront aberrations of the Luch facility are compensated for with an adaptive system developed on the basis of a multielement deformable mirror [12].

The scheme of the adaptive system of the Luch facility is shown in Fig. 1. It contains a deformable mirror with a control unit, the input and output wavefront sensors (WFSs), and a control computer. The input WFS measures the radiation wavefront at the input of the amplification path, while the output WFS measures the wavefront at the output of the amplification path.

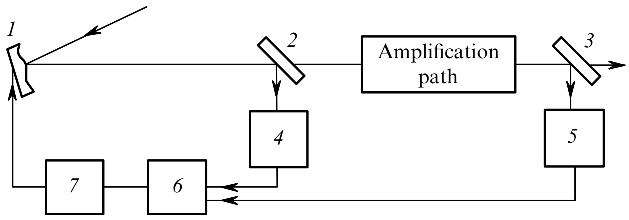

Figure 1. Scheme of the adaptive system: (*1*) deformable mirror; (*2*, *3*) plates directing radiation to WFSs; (*4*, *5*) input and output WFSs; (*6*) control computer; (*7*) deformable-mirror control unit.

The adaptive system of the Luch facility uses a multi-element bimorph piezoelectric deformable mirror (Fig. 2a) and a Hartmann WFS [13] (Fig. 2b). The latter consists of a matching telescope, a radiation attenuator, a kinoform raster, and a CCD camera. The kinoform raster is located in the plane conjugated with the plane of the deformable mirror and is attached to the CCD camera with the help of an adapter ring. The function of the raster in the WFS is to produce a system of focal spots on the CCD camera array. The wavefront surface is reconstructed from the magnitude of displacements of focal spots from the nodes of the ideal grid.

The wavefront distortions at the input of the amplifier path of the facility are estimated by measuring first the wavefront of the 1.053-μm input laser radiation pulse, which is straightened by the deformable mirror if needed. Then, the radiation wavefront is analysed at the amplifier output with the help of the output WFS, and the distortions are

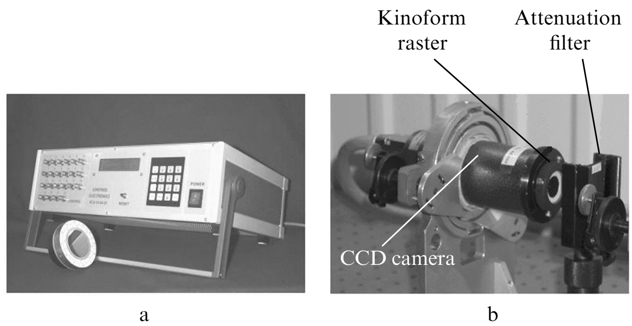

Figure 2. Photographs of the main elements of the adaptive system: deformable mirror with a control unit (a) and wavefront sensor (b).

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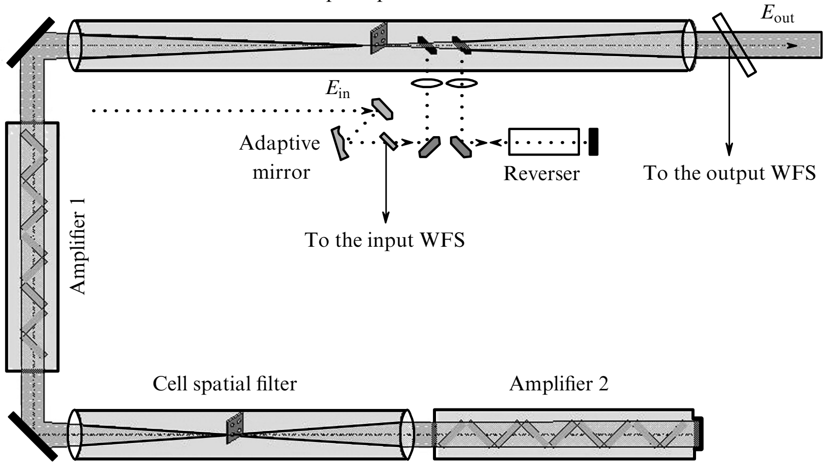

Figure 3. Scheme of the Luch facility.

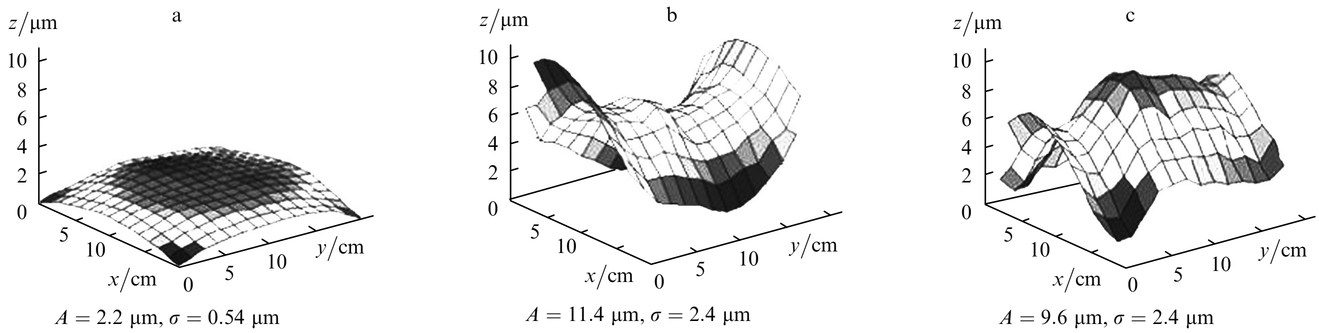

Figure 4. Aberrations of laser radiation wavefront at the input of the amplifier path (a), static aberrations of the amplifier path (b), static and 'thermal' aberrations of the amplifier path (c) (z is the phase in optical path units).

determined in the optical path for 'cool' amplifiers 1 and 2 (Fig. 3) [4]. After measuring the static wavefront distortions, the total distortions in the amplification path upon pumping amplifiers 1 and 2 are measured. Taking into account the obtained static and dynamic wavefront aberrations, 'pre-distortions' are introduced into the deformable mirror to compensate for the wavefront aberrations at the laser output in the operating mode.

Figure 4 shows the results of wavefront measurements of the laser radiation at the input and output of the amplification path of the Luch facility. The wavefront is characterised by two parameters: the aberration amplitude A and the standard deviation σ.

The wavefront at the input of the amplification path slightly deviates from the smooth one: $A = 2.2$ μm, $\sigma = 0.54$ μm (Fig. 4a). The static aberrations of the amplification path (Fig. 4b) were measured by recording the pulsed radiation without pumping the amplification stages. The maximum aberrations were observed at the aperture edges. Figure 4c presents the total (static and 'thermal') aberrations measured for the pulsed radiation when amplification stages 1 and 2 were pumped for a voltage across the capacitor bank $U_p = 18$ kV, which provided the gain $g_0 = 3.7 \times 10^{-2}$ cm^{-1}.

One can see from the above data that the amplitude of total wavefront aberrations upon pumping the amplifiers is $A = 9.6$ μm and the standard deviation is $\sigma = 2.4$ μm, which is smaller than in the case of static aberrations ($A = 11.4$ μm, $\sigma = 2.4$ μm), i.e. the 'thermal' aberrations partly compensate for the static aberrations of the amplification path.

We calculated the control voltages for the deformable mirror from the measured wavefront parameters and corrected wavefront aberrations of the high-power radiation of the Luch facility. Figure 5 shows the wavefront surfaces and experimental far-field radiation intensity distribution patterns at the output of the amplification path measured before the voltage application and after three iterative corrections of the voltage applied to the deformable mirror. One can see from Fig. 5 that after three corrective iterations of the voltage applied to the deformable mirror the wavefront aberrations of the high-power laser decreased by a factor of ~ 3: from $A = 9.6$ μm, $\sigma = 2.4$ μm to $A = 3.2$ μm, $\sigma = 0.6$ μm. The angular energy distributions at the facility output under ordinary conditions and with the compensation of distortions by the adaptive system are presented in Fig. 6.

One can see from Figs 5 and 6 that the radiation distribution pattern obtained by using the adaptive system became more symmetric and the radiation divergence measured at the 0.8 level decreased by half.

Therefore, the adaptive system containing a multielement controllable deformable mirror used in the Luch facility reduced the wavefront aberrations of the amplification path of the facility by a factor of three and the angular radiation divergence by half.

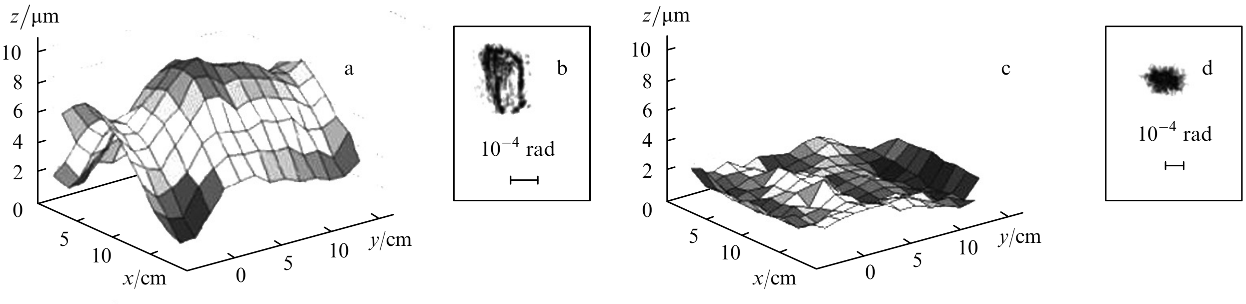

Figure 5. Results of the wavefront aberration correction for the high-power laser for $U_p = 18$ kV (a, c) and far-field radiation intensity distributions (b, d) before the application of voltage to the deformable mirror (a, b) and after three iterative voltage corrections (c, d) (z is the phase in optical path units).

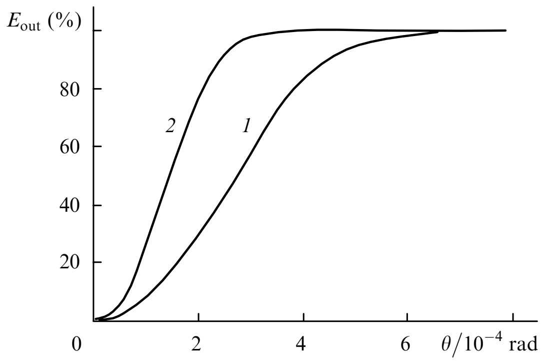

Figure 6. Angular energy distributions E_{out} at the facility output under ordinary conditions (*1*) and with the distortion correction by the adaptive system (*2*); θ is the divergence angle.

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