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Channel of a high-power laser fusion Luch facility emitting 3.3-kJ, and 4-ns pulses

S.G. Garanin, A.I. Zaretskii, R.I. Il'kaev, G.A. Kirillov, G.G. Kochemasov, R.F. Kurunov, V.M. Murugov, S.A. Sukharev

***Abstract*. The amplification of weak 80 – 240-mJ, 4-ns laser pulses with a gain of 0.035 – 0.045 cm^{-1} is studied. The maximum energy of 3.3 kJ is obtained for 4-ns pulses.**

Keywords: *neodymium phosphate glass, disk element, linear gain, radiation energy*.

The principal element of the high-power NIF [1], LMJ [2], and 'Iskra-6' [3] laser facilities constructed for the investigation of the physical principles of operation of laser fusion targets is multipass power amplifiers involving disk elements of neodymium phosphate glass. The limiting output laser energy of these facilities is determined by parameter optimisation of all systems of the amplification path, including the radiation resistance of the optical elements, the B-integral value, the small-signal gain g_0, etc. In this case, the average output energy density $\varepsilon_{\rm out}$ achieved for optimised laser channels amounts to $\sim$10 J cm^{-2} for a pulse duration of $\sim 3 - 5$ ns (see, for instance, Ref. [4]).

The laser systems of multichannel facilities [1 – 3] are optimised on the prototype amplification modules developed at laser centres [5 – 7]. At the All-Russian Scientific-Research Institute of Experimental Physics, a four-channel Luch facility [7] was built to verify and work out the scientific and technical solutions of vital significance to the Iskra-6 facility, which has the following parameters: a total energy of 300 kJ, a wavelength of 0.351 μm, and a pulse duration of 3 – 5 ns.

In this paper we present the results of the optimisation of all systems of the laser channel of the Luch for achieving the maximum output energy [8]. The four-pass amplification path of the Luch facility (Fig. 1) contains two power amplifiers 1 and 2 separated by a cell spatial filter. The injection of radiation into amplification path, its return for the third passage, and its extraction after the fourth passage are effected via a transport spatial filter. Apertures with four openings are located in the focal planes of the lenses of both spatial filters. In each of the four passages, the laser beam passes through an opening of its own. Each of power amplifiers 1 and 2 consists of nine standard modules shown in Fig. 2 with a flashlamp pump system common for the four channels. Rectangular disk elements are made of neodymium phosphate KGSS 0180 glass [9].

Calculations have shown [3] that to obtain an average output energy density $\varepsilon_{\rm out} \sim 10$ J cm^{-2} in this configuration, the gain $g_0 \approx 0.04 - 0.05$ cm^{-1} should be provided. In [10, 11], the experimental technique and the gain measurements on the Luch facility were reported. These investigations demonstrated that the power amplifier design permitted obtaining $g_0 \approx 0.05$ cm^{-1} in the standard regime. Another prerequisite for achieving the maximum output energy is a proper selection of passive and active optical elements of the amplification path which would possess the required radiation resistance. Special experimental investigations carried out using the test benches of the Russian Federal Nuclear Centre and the Research Institute of Full-Scale Tests of Optic-Electronic Devices and Systems (Sosnovyi Bor, St. Petersburg region) [12] showed (Table 1) that the radiation resistance of virtually all elements allowed studying the amplification of a laser pulse without damage under rated conditions. The exception was the input and output lenses of the transport filter, whose antireflection coatings had a damage threshold close to the operating load of $\sim$10 J cm^{-2}.

In large-scale neodymium-glass laser facilities under development, of fundamental significance is the minimisation of static and thermally induced wave-front aberrations, which underlies the achievement of high laser-radiation energy densities at the target. On the other hand, lowering the radiation divergence permits optimising the diameters of the apertures of spatial filters for reducing the self-focusing threshold. The results of experimental investigations aimed at decreasing the radiation divergence and wave-front aberrations of the Luch facility are reported in Ref. [13]. These experiments enabled decreasing the radiation divergence by a factor of two ($\theta_{0.8} \approx 2 \times 10^{-4}$ rad), which in turn resulted in the reduction of the aperture diameter from 2.5 to 1.5 mm for a focal distance of the lenses of the spatial filter of 7 m.

The spatial distributions of laser radiation intensity prior to and after the optimisation are shown in Figs 3 and 4, respectively, which demonstrate the decrease of small-scale intensity modulation by a factor of $\sim$3.5.

S.G. Garanin, A.I. Zaretskii, R.I. Il'kaev, G.A. Kirillov, G.G. Kochemasov, R.F. Kurunov, V.M. Murugov, S.A. Sukharev All-Russian Scientific Research Institute of Experimental Physics – Federal Nuclear Centre, prosp. Mira 37, 607190 Sarov, Nizhnii Novgorod region, Russia; e-mail: zaretski@otd13.vniief.ru;
R.F. Kurunov D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, Federal State Unitary Enterprise, pos. Metallostroi 3, 189631 St. Petersburg, Russia; e-mail: kurunrf@mit.niiefa.spb.su

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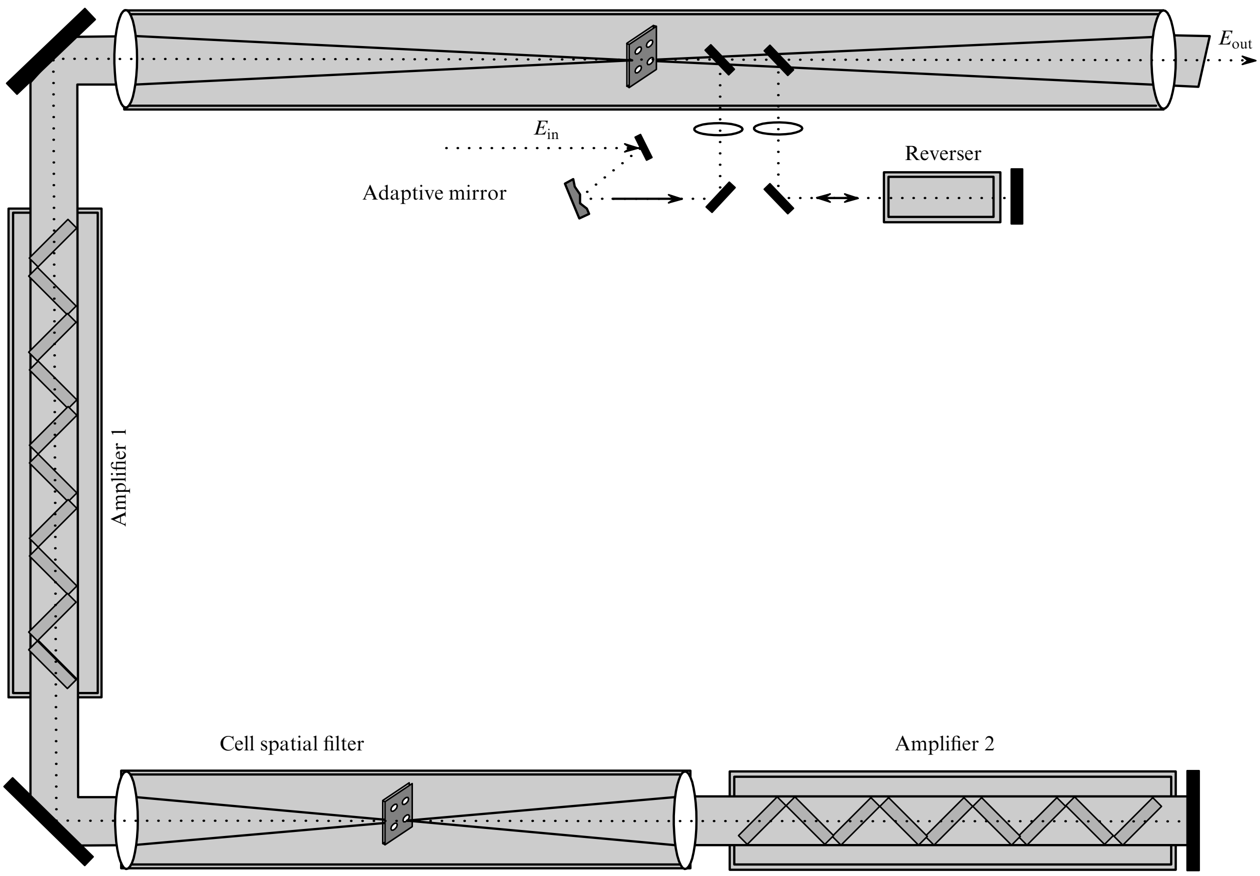

Figure 1. Scheme of the Luch facility.

The calculated pulse amplification in the facility channel is presented in Fig. 5. The calculations took into account the passive losses in the disk elements, the amplifier windows, and the lenses of the spatial filters, the mirror reflection coefficients, and the transmission coefficients of the reverser path. The four-pass path transmission in the amplifier measured in the absence of pumping and for an empty reverser was equal to 10 %. The nonlinear refractive index n_2 used in the calculation of the B-integrals was taken to be equal to 1.05×10^{-13} esu. The effective area of the beam aperture was equal to 320 cm^2 (80 % of the $20 \times 20 = 400$ cm^2 area). The calculation is based on the balance approximation using the effective energy saturation density of

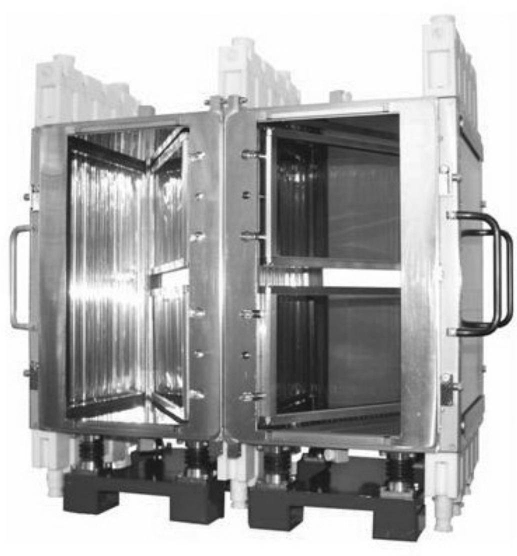

Figure 2. Photograph of a standard four-channel amplification module with disk elements, pump flashlamps, reflectors, and protective glass.

Table 1. Results of radiation resistance tests of the optical elements developed for the Luch facility (the laser pulse duration is $\tau_{0.5} = 3$ ns).

Tested object	Damage threshold/J cm^{-2}	Working load/J cm^{-2}
Output surface of the K-8 glass	29 – 32	10
KDP crystal volume	26	10
Output surface of a KDP crystal	27	10
Dielectric mirrors*	8 – 10	1 – 4
Dielectric antireflection coatings	6 – 8	1 – 4
Output surface of the KGSS 0180 glass (disk element)	26 ± 5	to 10
Working surface of an adaptive mirror	5 – 8	0.1

*The recently made tests of the dielectric mirrors produced by the Research Institute of the Luch Research and Production Association showed that their radiation resistance corresponds to the radiation resistance of the K-8 glass.

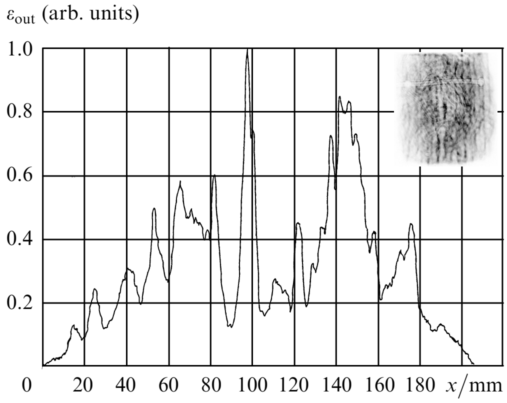

Figure 3. Near-field region (in the inset) and laser-radiation energy density distribution over the horizontal beam section prior to optimisation.

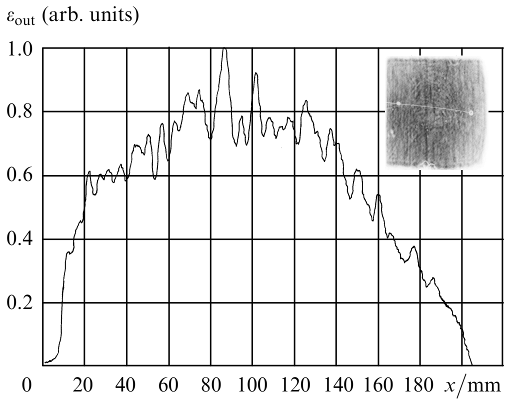

Figure 4. Near-field region (in the inset) and laser-radiation energy density distribution over the horizontal beam section after optimisation.

4.7 J cm^{-2}. This value was measured for the American LG-750 glass [4], which similar to the KGSS 180/35 glass in composition [4].

The radiation energy at the channel output was measured with Molectron J25 and Gentec ED-200 pyrocalorimeters. The information was displayed on a Molectron EPM 1000 energy meter and a Gentec DUO power meter, respectively. The far- and near-field radiation patterns were recorded with 18.56 × 16.64-mm Electron-M

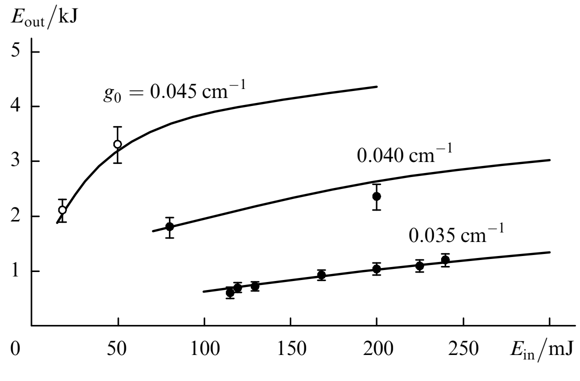

Figure 5. Radiation energy E_{out} at the output of the Luch facility channel as a function of input energy E_{in} for different linear gains g_0 (curves – calculation, points – experiment).

12-bit SIR-05-M CCD cameras (with a pixel size of 16 × 16 μm) and a dynamic range of 500.

Figure 5 also shows experimental data on pulse amplification ($\tau_{0.5} = 4$ ns) for small linear gains ($g_0 = 0.035$ and 0.040 cm^{-1}) for an input signal energy of 80 – 240 mJ. One can see that the experimental data are in agreement with the calculated dependence and the output energy does not exceed ~2.3 kJ in the input energy range under study.

To achieve the required output energy in the channel (~3 – 4 kJ), the experiments on signal amplification were carried out for $g_0 = 0.045$ cm^{-1} [11]. For input energies of 20 and 50 mJ, the output energies were equal to 2.1 and 3.3 kJ, respectively, the experimental data being in reasonable agreement with the calculated dependence (see Fig. 5). The duration of the radiation pulse at the facility output was $\tau_{0.5} \approx 4$ ns. The radiation density distribution over the beam section has a speckle structure typical of high-power neodymium facilities operating near the self-focusing threshold [4, 14]. This distribution is caused by the nonlinear growth of small-scale perturbations during amplification due to the nonlinearity of the refractive index, the insufficient angular filtration, and scattering from the optical elements in the amplification channel.

Therefore, the study of the angular radiation selection, the introduction of an adaptive system, and the improvement of disk element pump efficiency have allowed us to obtain the output energy of 3.3 kJ from in the amplification channel of the Luch facility (for the gain $g_0 = 0.045$ cm^{-1} and the input energy of 50 mJ) for a 4-ns laser pulses with the divergence $\theta_{0.8} = 2 \times 10^{-4}$ rad.

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