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OPTIMIZATION OF THE MASTER OSCILLATOR LASER BEAM PARAMETERS IN THE MULTI–PASS AMPLIFIER

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Abstract

Some results devoted to development of the ITEP laser–plasma ion source for a charged particle accelerator are presented. In our case, the laser radiation source is a high-power repetition rate CO_2 laser system based on the nonlinear interaction of a light with a multi-pass amplifier medium. The laser chain consists of a master oscillator [1], gas absorber cell, and a four–pass amplifier.

The efficiency of the laser ion source depends on by the output power of laser setup. The output power of such a laser setup is determined by the efficiency of energy extraction from the amplifying medium.

The spatial parameters of a laser beam at the amplifier input are optimized by numerical simulation. The results obtained for fixed master oscillator pulse and amplifying medium parameters. The maximum output energy is achieved with certain laser beam profile at the amplifier input. For this purpose, only central part of the beam with a Gaussian spatial profile, which is close to uniform in intensity, is injected into the telescopic amplifier. The optimal choice of beam diameter ensures the maximum laser efficiency.

INTRODUCTION

A laser-plasma generator of multiply charged ions based on a CO_2 laser is useful for a wide range of practical applications, including as a source for an particle accelerator. A such repetitive rate laser has a relatively low cost and is capable of emitting a pulses with a power of over 5 GW and an energy of over 100 J. A low operating costs, a relatively weak requirements for cleanliness degree, thermal stabilization and dust–free premises is a undeniable advantage of a such laser.

The laser–plasma generator based on a CO_2 laser was developed for the lead ion source for the CERN accelerator [2] and for the ITEP–TWAC facility [3]. In the above examples, a laser–optical scheme based on nonlinear effects during propagation of radiation pulses in absorbing and amplifying resonant media [4] was used.

EXPERIMENTAL SETUP

The optical scheme of the experimental setup is in the Fig. 1. The master oscillator (1) is based on a self-sustained discharge module at atmospheric pressure with UV preionization. The hybrid generation scheme of the generator is required to form single–frequency laser pulses with a smooth temporal shape and an FWHM pulse duration of 80 ns and energy up to 200 mJ for the P(20) line in the 10-μmetre band. The sectioned absorber gas cell (2) [5] of 90 cm length is filled with a mixture of SF_6/N_2 and is used to modify the master oscillator pulse front edge. The grating (3) separates the master oscillator and the amplifier medium for the entire spectral range except the desired spectral line.

The spatial parameters of the laser beam are defined by a spatial filter that consists of a pair of confocal mirrors (4, 6) and diaphragm (5). The laser beam formed by the filter is close to a Gaussian beam. In the laser setup a four–pass amplification chain is applied. It is arranged with flat mirrors and a pair of mirrors (8, 10) of a Cassegrain off–axis telescope with multiplication $M = 5.5$.

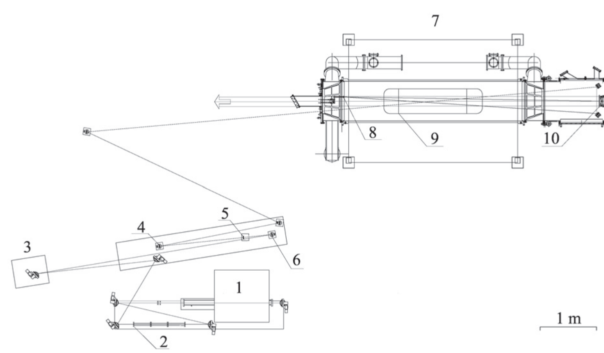

Figure 1: Experimental setup. 1 — master oscillator; 2 — absorbing cell; 3 — diffraction grating; 4 — short–focus mirror of the spatial filter; 5 — spatial filter diaphragm; 6 — long–focus mirror of the spatial filter; 7 — wide-aperture four–pass amplifying module; 8 — small telescope mirror; 9 — active medium; 10 — large telescope mirror.

SPATIAL PARAMETERS OF THE LASER BEAM CALCULATION

The computer program FOCUSD [2] for analysis of the laser beam spatial distribution in the laser beam shaping scheme describes the distribution of the light energy density in the 1D diffraction approximation in the case of cylindrical symmetry and integrally over time. Active medium gain is uniformly $g_0 = 2.5 \times 10^{-2}\,\mathrm{cm}^{-1}$. An absorbing cell influence is described according to the previously developed phenomenological model of an absorbing medium [6].

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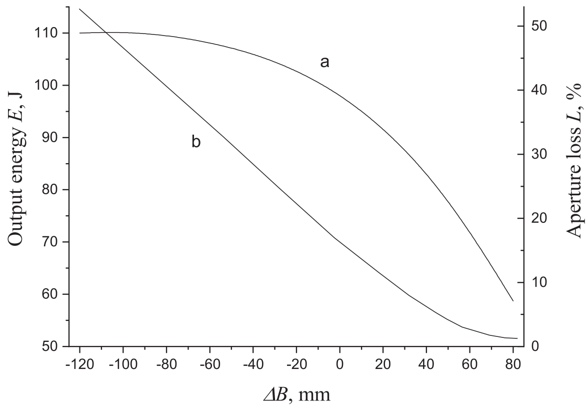

Figure 2: The calculated output energy (a) and aperture losses at the small mirror of the amplifier telescope (b) in dependence on the the spatial filter base detuning ΔB.

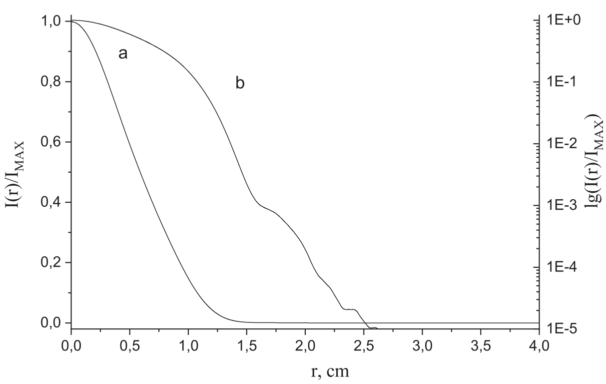

Figure 3: The calculated laser beam energy density distributions on the small mirror of the amplifier telescope. The spatial filter base detuning is +80 mm.
a — in a linear scale; b — in a logarithmic scale.

RESULT AND DISCUSSIONS

The calculated output energy and aperture losses at the small mirror of the amplifier telescope in dependence on the the spatial filter base detuning is presented in Fig. 2.

The radial energy distributions of the beam at the small mirror of the telescope for the different spatial filter detuning is presented in Fig. 3 (a converging beam) and Fig. 5 (a diverging beam). The radius of the small mirror of the telescope is 15.5 mm. The corresponding radial energy distributions of the beam at the amplifier output is presented in Figs. 4 and 6. In this cases, the output energy is 59 and 110 J respectively.

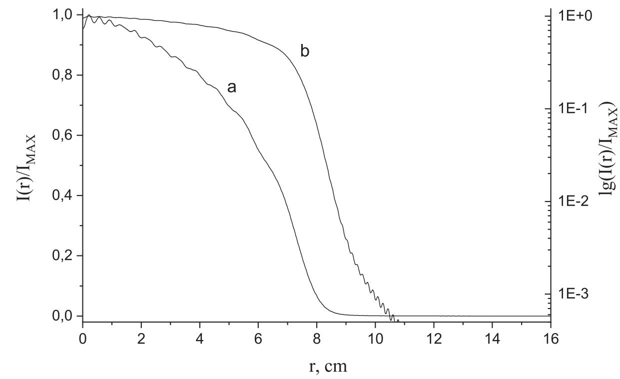

Figure 4: The calculated laser beam energy density distributions at the amplifier output. The spatial filter base detuning is +80 mm.
a — in a linear scale; b — in a logarithmic scale.

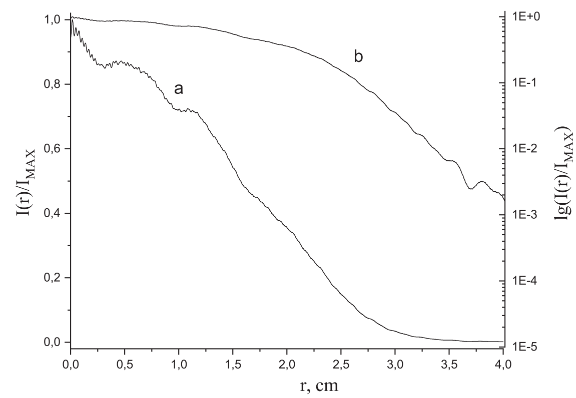

Figure 5: The calculated laser beam energy density distributions on the small mirror of the amplifier telescope. The spatial filter base detuning is −100 mm.
a — in a linear scale; b — in a logarithmic scale.

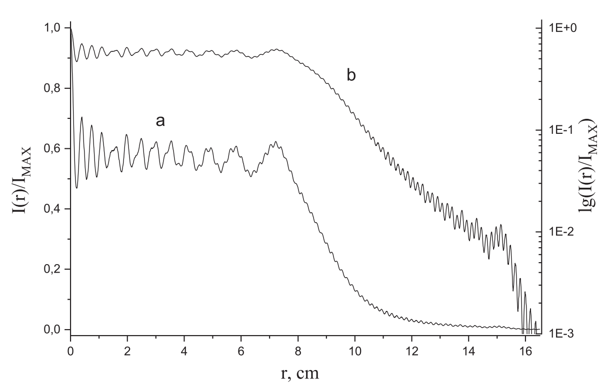

Figure 6: The calculated laser beam energy density distributions at the amplifier output. The spatial filter base detuning is −100 mm.
a — in a linear scale; b — in a logarithmic scale.

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CONCLUSION

The results of diffractional calculation of the laser optical scheme have shown that the maximum output beam energy is obtained with a certain beam diameter on the small mirror of the telescope.

The optimal tuning is reached with an increase of beam diameter relative to the diameter of the small mirror, so that the input beam acquires a more uniform profile due to using of the central part of the Gaussian master oscillator beam, despite the increasing aperture losses. Further improvement of uniformity of beam energy density profile is achieved in this geometry of the amplification circuit in saturated passages of the amplifier.

As calculations in earlier works have shown, in this case, a pulse duration "compression" is more efficient and a higher output power is achieved. Output power of a laser pulse is crucial in applied problems such as ion beams generating in a laser–plasma ion sources. It determines of a laser plasma ionization degree and the number of generated ions.

Actual laser scheme differs from the model of amplifying medium used in numerical calculations by significantly inhomogeneous gain coefficient profile over the active medium cross section, results of calculations are in qualitative agreement with observed effects.

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