Specificities of laser pulse amplification in multi-pass amplifiers

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Abstract—The laser pulse amplification was considered with accounting temporal and spatial profiles under various pulse parameters. It was shown that using of multiple passes amplifier allows increasing efficiency and reducing temporal profile distortion. The possible ways to decreasing of temporal profile distortion were considered.

Keywords—laser pulse amplification

The increase of laser pulse passes number is a very attractive method to attainment of high efficiency of laser systems [1] especially for lasers based on disk active elements (AE). But the problem of suppression pulse profile distortions becomes particularly important in such laser systems due to enlargement of interaction length [2].

The numerical simulation of laser pulse amplification can be carried out by both Franz-Nodvig formula and numerical solution of rate equation for pulse intensity and population difference. Both methods provide very close result in considered case but the last one allows keeping non-uniform population difference distribution and can be used for amplification simulation within previously developed software for modeling energy storage [3].

In order to describe temporal profile distortion we introduced the next characteristic named pulse front rolling

\[ N = \frac{I_{\text{after}}^A}{I_{\text{before}}^A} / \frac{I_{\text{after}}^B}{I_{\text{before}}^B} \] (1)

where \( I_{\text{after}} \) and \( I_{\text{before}} \) are pulse intensity at the pulse centre after and before amplification correspondingly, and A and B represent initial and final part of the laser pulse. The pulse rolling is always greater or equal than 1, the case of equality corresponds to absence of pulse temporal distortion.

In the simulation the Gaussian temporal profile of the laser pulse was considered with duration to be equal 2 ns. The active element was assumed to be an axially symmetric volume with homogeneous population difference distribution. Three multiple pass amplifiers schemes were considered.

The amplifier demands to provide pulse amplification up to certain output energy \( E_{\text{out}} \), as initial condition either active element stored energy or initial pulse energy is known. In order to investigate pulse rolling dependence on passes number three cases with fixed output energy \( E_{\text{out}} \) were considered: (a) single pass of laser pulse with initial energy \( E_n \) through AE with stored energy is \( E_{\text{st}} \); (b) several passes of the laser pulse through AE with fixed stored energy \( E_{\text{st}} \), initial energy is varied; (c) several passes of the laser pulse with initial energy \( E_{\text{st}} \) through the AE; stored energy is varied.

In the case (b) the same efficiency as in case (a) can be obtained for any number of passes. In case (c) the efficiency grows with increasing the number of passes and theoretically it is possible to extract stored energy completely.

It was shown that pulse rolling demonstrates different behaviour for Gaussian and rectangular radial profiles. As for rectangular laser pulse it is impossible to decrease value of \( N \) with increase of passes number. The rolling for case (b) is greater or equal to the one for case (a) while \( N \) for case (c) is identical with this value for single pass. The Gaussian pulse demonstrates possibility to decrease of the pulse rolling with increasing of pulse passing number in case (c). In this case radial pulse profile tends to reproduce pump profile what can be treated as additional advantage of multi-pass scheme. The pulse rolling for (b) case is close to the one for single pass.

Unfortunately, the suggested methods are aimed only to compensate \( N \). But according to our calculations there are possibilities to decrease pulse rolling in case of chirped pulses. For this purpose the amplification of the chirped pulse with emission cross-section slope can be used. The initial part of the laser pulse experiences amplification in that spectrum wavelength range which has emission cross-section smaller than at maximum. Thus, amplification of initial pulse part does not lead to dramatic population difference depletion and final part of the pulse can be amplified sufficiently. The other approach to pulse rolling decreasing is inversion of group velocity dispersion between amplifiers.

REFERENCES