2D MODELING OF THERMAL SMOOTHING OF LASER IMPRINT IN A DOUBLE-PULSE PLASMA

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Abstract

Laser prepulse effect on thermal smoothing of non-uniformities of target illumination is studied by means of 2D Lagrangian hydrodynamics simulation, based on the parameters of a real experiment. A substantial smoothing effect is demonstrated for the case of an optimum delay between the prepulse and main heating laser pulse. The cause of enhancement of thermal smoothing effect by laser prepulse is the formation of long hot layer between the region of laser absorption and the ablation surface. Comparison with experimental results is presented.

1. Introduction

In the laser inertial fusion studies a very smooth ablation pressure profile is required (typically up to a few per cent) to suppress the onset and a subsequent growth of Rayleigh-Taylor instability, which might disrupt the target compression. The ablation pressure inhomogeneity arises due to an inhomogeneous illumination of the target by the heating laser beams. Beside an improvement of the illumination profile other smoothing mechanisms have been proposed, which are based on a modification of the laser-target interaction. A very powerful intrinsic smoothing mechanism is hidden in the plasma itself due to the presence of heat conduction zone between the region of laser absorption and the ablation surface [1,2]. The laser beam energy, which is deposited in the underdense plasma, is then transported to the target by the thermal conduction. The thermal transport is taking place not only in the longitudinal, but also in the transverse direction. Any inhomogeneity in the distribution of absorbed energy has thus a tendency to be washed out when the heat is conducted across the conduction zone.

The distance between the absorption region and the ablation surface is controlled by stretching the space between the target and the impinging beam. This can be done either by covering the target with a layer of a low density plastic foam or by using a prepulse, which produces a thin plasma region prior to the arrival of the main pulse. The last mechanism was shown to work using an iodine laser driver with a converted beam. The prepulse plasma produced by a $2nd$ harmonics (red) beam smoothed out the main $3rd$ harmonic (blue) beam profile following a fraction of nanosecond later. In order to demonstrate the effect the blue beam was split in two foci, which were placed in a larger red prepulse spot [3], following a scheme originally proposed by Garanin, see Fig. 1.

The two focal spots had each 80% of 3.5 J energy confined inside 20 μm radius within a larger background plasma created by the prepulse of 6 J in energy. The distance between the spot centers was 80 μm. The prepulse of the $2nd$ harmonics of iodine laser had a circular focus with a radius of 100 μm. Both the laser pulses were incident normally onto an Al foil with a thickness of 7 μm. The temporal shape of both the laser pulses was close to a Gaussian form with a pulse duration of 0.5 ns FWHM, with three delays (0, 0.5, 1 ns) of the main pulse with respect to the prepulse.
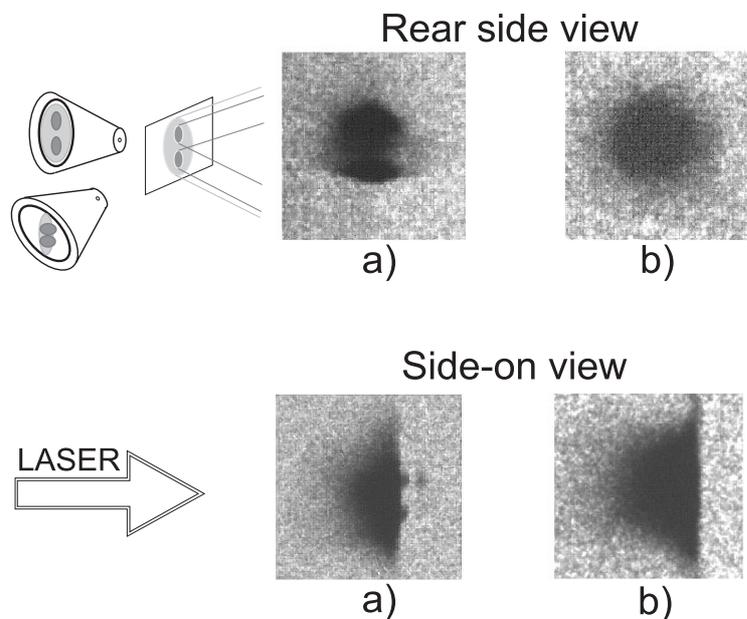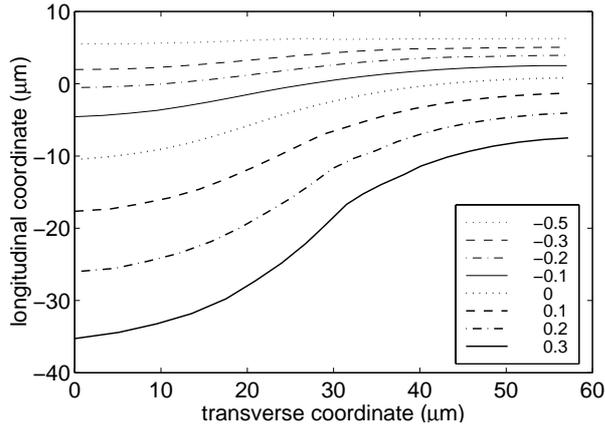

Fig. 1. Time integrated pin-hole camera pictures of the plasma (rear side and side-on views). a) red prepulse absent, b) red prepulse advancing by 0.5 ns.

In this contribution the phenomenon of prepulse smoothing is modeled by means of 2D hydrodynamic simulation of the laser-plasma interaction, using a cylindrical version of Lagrangian code "ATLANT" [4]. The parameters of the model were derived from the real experiment of the double pulse illumination of Al target foil by the iodine laser. Since the geometry of the code is restricted to the cylindrical symmetry, this study is limited to the simulation of a single blue laser spot on the background of a much broader red prepulse. Three different time delays (0, 0.5 and 1 ns) between the prepulse and the main pulse were analyzed to search for an optimum delay setting for the thermal smoothing of inhomogeneities in the target illumination. The code has been used before to model a similar problem in the spherical geometry [5].
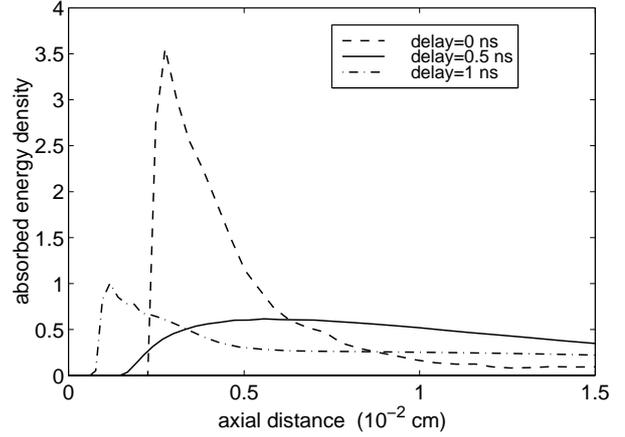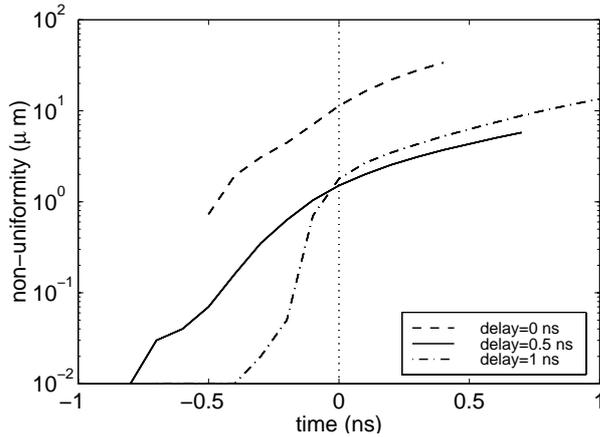
2. Numerical model

The thermal smoothing of the *single* blue laser spot is simulated by the 2D Lagrangian hydrodynamics code "ATLANT" [4] in the cylindrical geometry. The code incorporates a two temperature approximation with classical and flux-limited electron and ion thermal conductivities. Collisional absorption of laser beams is calculated by means of ray-tracing algorithm, a full absorption at the critical surface is assumed. A constant mean ion charge $Z = 12$ is taken for the Al foil. A homogeneous radial distribution of the prepulse was used in the simulations to simplify the comparison of results for different main pulse delays by avoiding non-uniformities induced by the prepulse. As in our model all energy is absorbed we take into account the fraction of the absorbed laser energy by multiplying the experimental values of laser intensity by the absorption efficiency 0.5 for the red beam and 0.7 for the blue one. A Gaussian spatial profile for the blue spot is assumed.
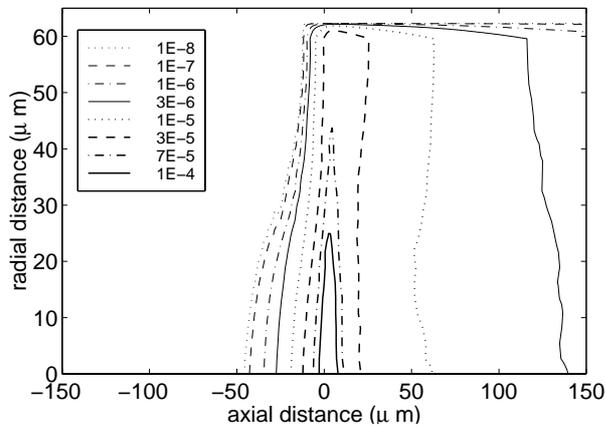
Fig. 2. Example of a computed evolution of the maximum compression surface (shock-wave) for the time delay 0 ns between the prepulse and the main pulse. Parameter: elapsed time with respect to the maximum of the main pulse.

Fig. 3. Time growth of the longitudinal inhomogeneity size (bulging) for 3 different delays.

Fig. 4. Example of a time integrated x-ray image for the time delay 0 ns.

Fig. 5. Absorbed laser energy in dependence on the axial distance from the target for 3 different delays.

3. Results

In Fig. 2 profiles of surfaces of the maximum compression for different moments of time is presented. They prove the effect of heat smoothing. Although inhomogeneities are not suppressed completely they are delayed and their growth rate is reduced by the presence of the prepulse.

In Fig. 3 it is shown the rate of focus size time growth for different delays. The moment of maximum intensity of the 'blue' pulse was taken as the time zero. The growth rate dependence proves the existence of an optimum time delay between the prepulse and the main pulse: the rate of growth is higher for the 0 and 1 ns delays compared to the 0.5 ns delay.

In Fig. 4 we present numerical results of time integrated x-ray emission obtained from the side view in comparison with the experimental shots. Since the x-ray filter ahead of the pinhole camera had a cutoff energy of 0.6 keV, we integrated over the time the intensity function

$$I(t) = const \cdot \sqrt{T_e} \cdot \rho^2 \cdot \exp\left(-\frac{0.6}{T_e}\right),$$

where T_e is the electron plasma temperature

measured in keV and ρ is the plasma density. A reasonable agreement of the simulations with the experiment is demonstrated. For the time delay 0.5 ns the radial inhomogeneities are not seen in the integral x-ray emission and are reduced for the delay 1 ns. Owing to the reduced growth they occur only at the end of the laser pulse when the plasma is too cool to radiate an appreciable x-ray emission in the specified energy range.

Distributions of absorbed power per unit volume are presented in Fig. 5 at the temporal maximum of the main laser pulses for the three delays considered. It shows that the smoothing enhancement is caused by changes in the spatial distribution of laser absorption. In the case of suitably timed prepulse a long underdense plasma is formed where most of the absorption occurs. Thus the absorption region is shifted far from the critical surface to the corona. A relatively dense, long and hot layer of underdense plasma is promoting a good thermal smoothing. Moreover, it is to be expected that the laser reflection decreases in this situation, which could be verified experimentally.

4. Conclusions

The prepulse effect on the thermal smoothing was clearly demonstrated. Thermal smoothing cannot suppress the inhomogeneities completely but in the case of the optimum delay it reduces and delays their growth significantly.

We found that the effect is caused by a formation of long and hot layer between the absorption region and ablation surface. In the case of the optimum delay the main pulse energy is absorbed in the underdense plasma far from the critical surface. Thus the space between the critical and ablation surfaces in the presence of prepulse forms just a part of the entire heat conduction zone.

A qualitative agreement between the experimental and the calculated x-ray emission pattern was found. The best thermal smoothing is observed for the delay 0.5 ns both in the experiment and the simulations.

References

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