ACCELERATION OF THIN FOILS IN CHANNELS BY A LONG-PULSE SHORT-WAVELENGTH LASER

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Abstract

On the basis of estimates and 1D numerical calculation, it is shown that there is a possibility in principle of accelerating thin dense layers in channels to velocities of the order of 100 km/s by a long-pulse (~ 100 ns) short-wavelength (λ = 0.25 μm) laser. Calculated and experimental data (the latter were obtained using a GARPUN excimer laser at the P. N. Lebedev Physical Institute, Moscow) are compared.

A feasibility of using a krypton-fluorine laser with a pulse duration of 100 ns as a driver for a hybrid thermonuclear reactor was discussed in [1]. In such a high-power laser, one can practically attain an efficiency as high as about 10% with a 1-Hz pulse-repetition rate, which provides necessary conditions for completion of the power cycle in a thermonuclear power station. It was proposed to use a bilateral conical multi-layer laser target in order to reach thermonuclear temperatures and attain an appreciable compression of the target. It was shown that under a stable acceleration of a thin external metallic layer in a conical target channel one can provide conditions for a considerable neutron yield in a thermonuclear fuel as a result of the cumulation of the shock waves in the center of the cone. If conditions for stable acceleration of thin dense cold layers in a conical channel up to velocities of 200 km/s were provided, separate compression and initiation of thermonuclear reactions in conical targets could be possible [2]. Dynamic compression pressure in collisions of such layers with a barrier could attain more than 100 Mbar. Such an experimental setup could simulate separate effects occurring in collisions of celestial objects. The deceleration of accelerated layers by the barrier should initiate a high-power x-ray pulse.

The acceleration of thin foils in target channels by means of 20–30-ns pulses of an Nd laser was studied theoretically and experimentally in [3]. The possibility of achieving velocities up to 30–50 km/s was shown. However, the possibility of stable low-entropy laser acceleration of thin layers by means of a KrF laser has not yet been studied.

In this paper, we consider the possibility of acceleration of thin metallic foils in plane and conical channels by means of 100-ns pulses of an excimer laser. Estimates and numerical calculations have been performed for laser parameters similar to those realized in the GARPUN laser facility (P. N. Lebedev Physical Institute, Moscow) [4].

The calculations were performed with the help of the 1D Lagrange program DIANA, which allowed solution of the equations of gas dynamics, ion and electron heat conduction, and laser radiation transport as well as the radiation absorption due to Bremsstrahlung mechanism. The laser flux reaching a critical surface was absorbed in this layer [5]. The equations of state and the plasma ionization composition were allowed for within the model presented in [6]. Apart from the thermal pressure of electron and ion components of the plasma the contribution of the elastic component was taken into account in accordance with the TFC model [7]. The ion composition and the ionization losses were calculated in the average ion-charge approximation [8].

The 1D numerical calculations were made for the heating and acceleration of thin Al foils by means of a 0.25-μm KrF laser. The laser pulse had a trapezoidal shape with base durations of 0, 20, 80, and 100 ns.
Fig. 1. Plasma density (a) and velocity (b) as functions of the mass coordinate $M = \int \rho \, dx$, where $\rho$ is the plasma density at the instant $t = 80$ ns: 1) initial thickness of the layer $\Delta = 10 \, \mu m$, 2) $\Delta = 50 \, \mu m$, and 3) $\Delta = 5 \, \mu m$.

Radiation intensity at the trapezoid apex was $2 \cdot 10^{12}$ W/cm$^2$. The aluminum foils varied from 5 to 100 $\mu m$ in thickness.

The first set of calculations was made in Cartesian coordinates when all the parameters depended on a single coordinate $x$. Figure 1 illustrates the distribution of the plasma density as a function of the mass coordinate $M = \int \rho \, dx$, where $\rho$ is the plasma density at $t = 80$ ns for each of the three cases:

1) initial thickness of the foil is $10 \, \mu m$,
2) initial thickness of the foil is $50 \, \mu m$,
3) initial thickness of the foil is $5 \, \mu m$.

As seen from Fig. 1, three regimes of foil acceleration were realized in the calculations. In the first one, the unevaporated part of the foil retains a density higher than the initial, remains comparatively cold during acceleration (low entropy), and is accelerated up to 16–180 km/s (see Fig. 1b). In the second case, the shock wave does not have time to traverse the layer by the end of the pulse. As a result, after the end of the laser pulse some part of the material will fly to the right with approximately double the velocity of sound, and the evaporated low-density layers will move to the left. In the third case, the thermal wave heats up the whole layer, which leads to a high-entropy “exploding foil" regime. Approximately half of the material escapes to the left and half to the right. Figure 1 illustrates the situation at the instant of 80 ns, after which the radiation intensity decreases and the density of the unevaporated part of the foil in case 1 decreases as well.

Figure 1b demonstrates the velocities of the boundaries of the computational cells. The calculation was carried out for the case of Al foil with the initial thickness 10 $\mu m$. It is evident that the compressed layers escape with a velocity of above 100 km/s. Such a regime of acceleration is called a low-entropy one.

In the next set of calculations (case 4), the radiation intensity increased linearly up to the end of the pulse ($t = 100$ ns). The maximum intensity was $3.2 \cdot 10^{12}$ W/cm$^2$, so the pulse energy remained the same as in cases 1–3. Figures 2a and 2b show the distribution of the density and velocity of a 10-$\mu m$ foil accelerated by such a pulse (dashed line), and the density and velocity distribution in case 1. It is seen that a rising pulse makes it possible to increase somewhat the velocity, density, and pressure pulse ($\int \rho v^2 \, dx$) in the unevaporated part of the foil.