

ANALYSIS AND 2D NUMERICAL MODELING OF BURN THROUGH OF METALIC FOIL EXPERIMENTS USING POWER KrF- AND Nd LASERS

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1. Introduction

We have studied the burn through time of aluminum foils, which were illuminated by KrF and Nd lasers. Experimental investigations were made in the installations “GARPUN” (KrF-laser with energy up to 100 J and pulse duration 100 ns) [1] and “PICO” (Nd-laser with energy up to 30 J and pulse duration 4 ns) [2]. The numerical investigations were made by using 2D Euler code “NUTCY” [3].

2. 2D Euler code NUTCY and the tasks of computational modeling of foil burn-through experiments

The modeling of foil burn through effect with the help of traditional Lagrangian codes (for example, “ATLANT”-code [4]) has some difficulties. We are developing Euler 2D and 3D codes. It allows us to solve the problems of foil burn through, the input of a laser beam into a cavity [5] and other one. “NUT-CY”-code solves numerically the gas dynamic equations and electron heat conductivity in 2D cylindrical geometry (r, z, t). It is assumed that the laser beam is propagating strictly along the axis (OZ) and is absorbed due to bremsstrahlung mechanism. The laser flux which reaches the critical surface is absorbed in the cells. EOS is the ideal plasma.

3. The analysis of the experiments in GARPUN installation

High efficiency and scalability of e-beam pumped KrF lasers as well as a short UV wavelength make them very attractive for different laser-target interactions. The installation GARPUN produces the pulses of about 100 J energy and 100 ns duration. This enabled to obtain the laser beam with an angular width of ~ 0.1 mrad, axial power of 1.6×10^{17} W/sr and spectral brightness of 5×10^{15} W/cm² sr cm⁻¹. When being focused into a spot of 150 μ m it produced the peak intensity exceeding 5×10^{12} W/cm².

A number of laser-target experiments has been carried out in such conditions and compared with 2D numerical simulations. Fig. 1a illustrates the parameters the tasks for numerical simulations. These parameters suit the experimental conditions. The plasma and condensed matter flows were investigated by means of high-speed optomechanical and streak cameras in different time scales. In both cases the slit scanning of the images was used and schlieren or shadow schemes accompanied it. A collimated probe beam was formed by a pulsed capillary discharge source, and it was passed through an examined region near a target perpendicular to the laser beam. Typical time dependent records are shown in Fig. 1b. for the case of foil thickness equaling 250 μ m. Plasma produced at the irradiated target surface went away towards the incident radiation with a velocity 50-100 km/c. With a delay dependent on a target thickness and laser intensity plasma would appear at the backside of a target and also at

LASER DRILLING EFFECT

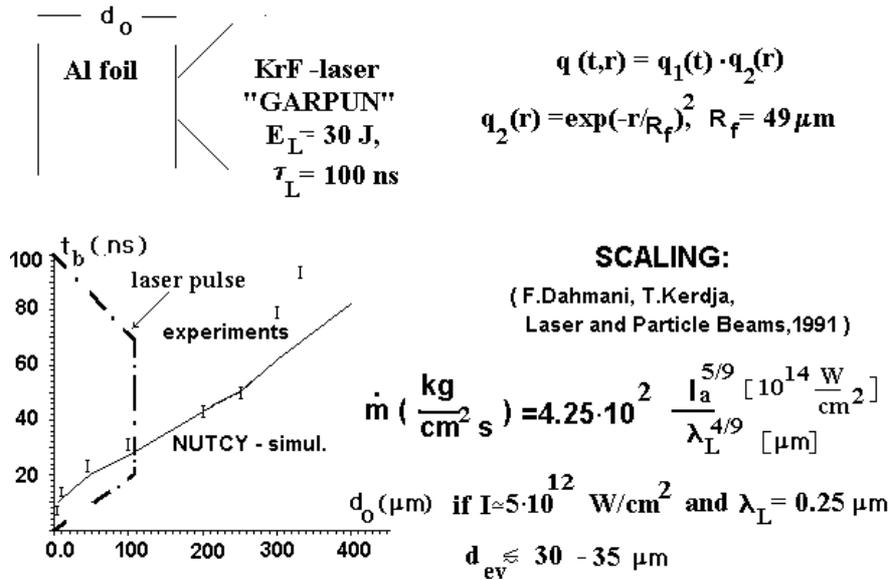


Figure 1.

The parameters of tasks and the results of 2D numerical simulations. The dependence of burn through time (t_b) of the foil thickness (d_0), "I"-experimental data, solid curve is the results of simulations.

the surface of a screen, which was placed behind to indicate that radiation penetrates through a target. Two plasmas expanding with compared velocities formed a well-defined shock wave after their collision. The dependence of burn-through time t_b on target thickness measured for aluminium is presented in Fig.1a together with the calculated one. They correspond to a fixed laser energy $E=30$ J or peak intensity $q=3.5 \times 10^{12}$ W/cm². The incident laser flux has been approximated by $q(t, r)=q_1(t) q_2(r)$, where $q_1(t)$ is a trapezium shown in Fig., and $q_2(r) = \exp(-r/R_f)^2$ is Gaussian form with a parameter $R_f=49$ μm corresponding to the experimental distribution in a focal spot.

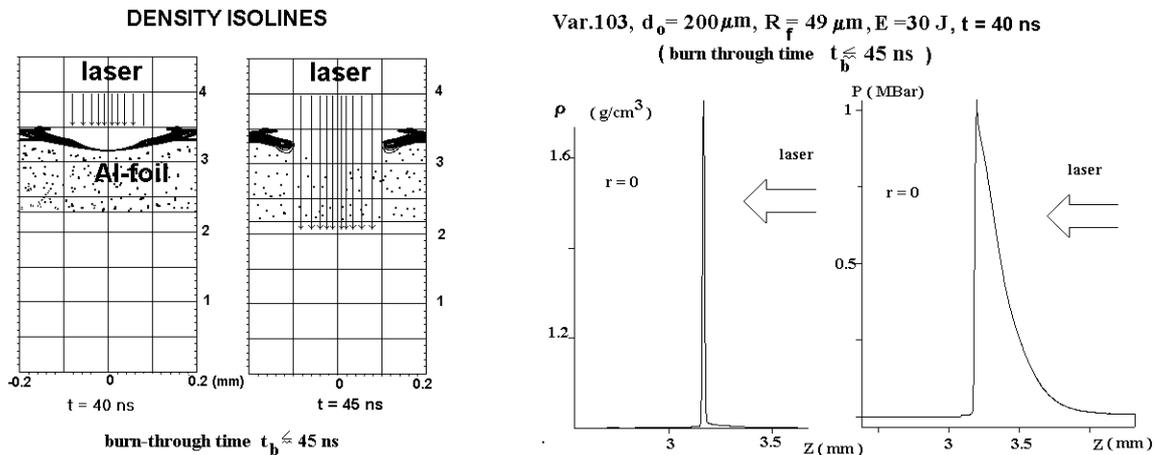


Figure 2. Variant 103. Density isolines for time 40 and 45 ns, (a). The distributions of density (ρ) and pressure (P) along 0Z-axis ($r=0$) at the moments $t=40$ and 45 ns (b).

Fig. 2a illustrates density isolines pictures. It shows that between 40 and 45 ns laser radiation burns through a target of 200- μm thickness (variant 103). Fig. 2b shows the distributions of density and pressure along 0Z-axis at the moments 40 and 45 ns. Between these moments density and pressure distributions drop rapidly. In [6,7] there is a scaling of mass evaporation rate of laser irradiated foils. In contrast to nanosecond laser pulses, where in one-dimensional conditions a burn-through time is determined by an ablation rate of target

material for 100 ns laser pulses a radial squeezing out of the matter contributes in the main to a hole burning of a target (“drilling effect”). This is confirmed by numerical simulation (Fig. 3) carried out for an increased in 2 times focal spot (parameter $R_f=100 \mu\text{m}$) and the same peak intensity, which indicates an increased up to 55ns burn-through time (variant 107). The results of burn-through time calculations for targets of a different thickness d_0 agree well to experimental data except $d_0 >250 \mu\text{m}$ (see Fig.1a). The reason of such discrepancy is the divergence of the laser beam, which became expanded in experiments outside the caustic of a focusing mirror.

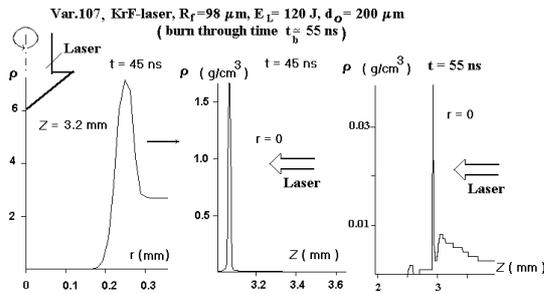


Figure 3. Variant 107. The diametrical (to the left, $Z=3.2 \text{ mm}$) and longitudinal (at $r=0$) distributions of density at $t=45 \text{ ns}$. The density distribution along $0Z$ -axis at $t=55 \text{ ns}$ (to right).

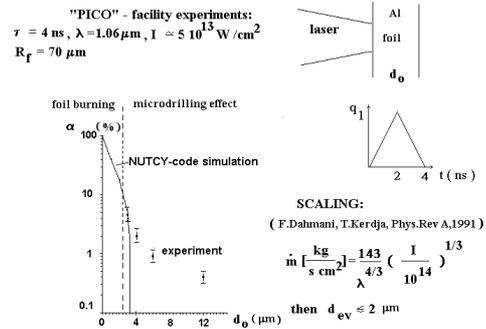


Figure 4. The parameters of the tasks. The comparison of 2D simulations (solid curve) and experiments (“ I ”), $\alpha=E_{th}/E_L$, d_0 - foil thickness.

4. The analysis of the experiments in PICO installation

The nanosecond Nd -laser was used. The laser pulse duration (FWHM) was 2 ns. The laser energy was changed from 2J to 20J correspondingly to the variation of flux density from 10^{13} to 10^{14} W/cm^2 on the target surface. The laser radiation divergence was $2\alpha = (5\div 8)\times 10^{-4} \text{ rad}$; the energy contrast ratio was $K_E = 10^4\text{-}10^5$. The laser spectral range (FWHM) was $\delta\lambda = 30\text{\AA}$.

It was developed special diagnostic equipment including automatic processing system for data from energy measuring calorimeter system and a set of coaxial photodiodes and automated system of laser radiation structure measurements in the target surface area. The developed diagnostics make it possible to produce simultaneous measurements of energy balance and specially and temporally resolved foil target burning through dynamics with the measurements of the laser radiation structure at the same time. This diagnostics configuration makes it possible to produce the correct interpretation of experimental results. The flux density was varied from 10^{13} W/cm^2 to 10^{14} W/cm^2 . The Al foils with thickness in the range from $3 \mu\text{m}$ up to $12 \mu\text{m}$ where used as a targets. The sharp dependence of the portion of laser energy passed through the target on foil thickness was observed. This phenomena was accompanied by relatively small decrease of the passed radiation pulse duration. The comparison of foil speed of burning through with published experimental data [7,8] and theoretical results, based on calculations with one-dimensional numerical code “DIANA” [9], show that the laser irradiation comes through the foil with thickness is 2-5 times larger then from mentioned data.

Using “NUTCY”-code 2D numerical simulations of laser interaction with thin Al-foils are performing. It is varied the thinness of foils. The laser pulse has triangular time-shape and depends on radius as $\exp(-(r/R_f)^2)$ (see Fig.4). The absorbed laser energy is 10 J. It defines the rate of laser energy coming through the foil (E_{th}) to the incident laser energy (E_L), $\alpha = E_{th}/E_L$. Fig. 4b shows the dependence of α from the thickness of foil d_0 . The symbols “I”

show the experimental data. To right it shows the scaling [8]. For the laser flux intensity $I \cong 5 \times 10^{13} \text{ W/cm}^2$ the evaporated layer of foil is about $2 \mu\text{m}$. Really, in 2D simulations we get burn through time $t_b = 2.8 \text{ ns}$ for the foil with thickness $2 \mu\text{m}$ ($\alpha = 18\%$) and $\alpha = 5\%$ for foil thickness $3 \mu\text{m}$. But there is no laser energy coming through the foil for the thickness more than $3.5 \mu\text{m}$ in the numerical simulations. The passed laser radiation (0,2%-5,0%) is observed in the experiments. It is carried a number of 2D simulations to model this effect. The time shape of laser pulse is a triangular as a earlier. The radius dependence of flux is

$$q_2(r) = (1 + a_0 \cdot \exp(-(r/R_f)^2)) / C_1. \quad C_1 \text{ is chosen under condition that } \int_0^{R_0} q_2 r dr = 1. \text{ We vary } a_0, R_f$$

and foil thickness. Fig. 5 shows the results of numerical simulations for the case $R_f = 10 \mu\text{m}$. The foil thickness is $4 \mu\text{m}$. The laser filament (or speckle) with $a_0 \sim 10$ come through the foil. The small scale (less than $10 \mu\text{m}$ in diameter) dashes of laser flux density (10-20 times more intensive than average) on the target surface have been observed in reported experiments. This "microdrilling effect" would be very dangerous for laser fusion targets. In [10-13] it is discussed the laser prepulse effect on thermal smoothing of non-uniformities of target illumination and this effect is demonstrated in laser-plasma experiments.

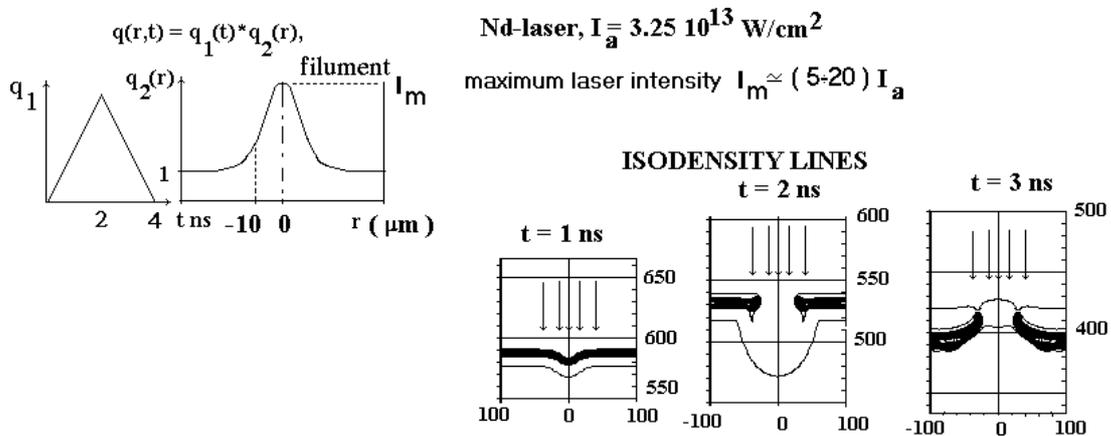


Figure 5. The parameters of tasks with filament effect (top) and calculation results. The density isolines at the moments $t=1, 2, 3 \text{ ns}$ (bottom).

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