

NUMERICAL SIMULATION OF THE EFFECTIVE INPUT OF LASER ENERGY INTO A CAVITY THROUGH A HOLE

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Abstract

A possibility of input of high-power laser pulse into a cavity through a hole was studied by means of 2D numerical calculations. Such tasks appear in view of investigation of the effective targets with internal input of energy [1,2], “cannon-ball” [3], “Greenhouse” targets [4,5].

We have used two Euler codes “NUTCY” [6] and “FAKEL” [7] to model the problems of laser beam input into a cavity through the holes.

1. Introduction

Using Lagrangian coordinates, one can simulate numerically high compressibilities and calculate with a high accuracy the position of contacting boundaries for two media with different densities and physical properties [8]. However, it seems to be rather difficult to take into account the plasma outflow through holes, which is associated with a strong distortion of Lagrangian cells (see [9]).

To take this effect into account, a two-dimensional numerical codes FAKEL and NUTCY were developed in spherical (r, θ, t) and cylindrical (r, Z, t) Euler coordinates.

2. The results of numerical simulation of greenhouse targets

In the first calculation series, heating and compression of such a target for the laser energy at the level of 100–200 kJ was simulated. We used FAKEL-code simulations. The target design is illustrated in **Fig. 1**. The exterior chamber of a spherical shape is made of lead (or gold) and has a radius of $R_0 = 1516 \mu\text{m}$ and a thickness of $6 \mu\text{m}$. It has also two holes near its poles (with the opening angle of $2 * \theta_1$) and a slit along the equator (with the opening angle $2 * \theta_2$). In this case, we simulate a situation when two laser beams propagated along the target axis, while a few ($\approx 4-6$) others passed through the equator. On the inner surface of the exterior chamber, there was a $10\text{-}\mu\text{m}$ polyethylene layer that partly prevented strong lead heating by a thermal wave going out from the absorber, R_4 , the inner radius of polyethylene layer. The initial absorber density was $2 \cdot 10^{-3} \text{ g/cm}^3$. The interior thermonuclear capsule with a radius of $910 \mu\text{m}$ and a thickness of $20 \mu\text{m}$ is made of polyethylene. A $20\text{-}\mu\text{m}$ layer of the DT ice was frozen on the shell inner surface. There is residual gas in its center. The laser beam with a wavelength of $1.06 \mu\text{m}$ was of the form $q_L = q_1(t) q_2(\theta)$.

The laser pulse increased with time linearly $q_1(t) = q_0 \frac{t}{t_0}$ where $t_0 = 2 \text{ ns}$ was its duration and $q_0 = 10^{14} \text{ W}$ was its intensity, so that the pulse energy was 200 kJ.

The calculation was performed in the region $0 \leq \theta \leq \pi/2$. The laser radiation was injected through holes in the poles and in the equator, the opening half-angles on the poles and equator being $0 < \theta < \theta_1$ and $\theta_2 < \theta < \pi/2$. The angular distribution of the laser radiation flux was given in the form

$$q_2(\theta) = \begin{cases} \frac{C_3}{\exp(\theta/\theta_3)^4} & \text{for } \theta \leq \theta_1, \\ 0, & \\ \frac{C_4}{\exp\left(\frac{\pi/2-\theta}{\theta_4}\right)^4} & \text{for } \theta_2 \leq \theta \leq \pi/2. \end{cases}$$

The parameters θ_3 and θ_4 are equal to $0.6\theta_1$ and $0.6(\pi/2 - \theta_2)$, respectively. The energy of the laser pulse was enhanced to 200 kJ.

Below it is given the results of the Greenhouse target simulations with the following parameters:

$$\theta_1 = \frac{\pi}{15}, \quad \theta_2 = \frac{8\pi}{9}.$$

The normalization parameters C_3 and C_4 were taken under condition of injecting 32.8 kJ of laser energy through the holes on the poles and the rest 167.2 kJ through the slot on the equator.

To the moment $t \approx 1.5-2$ ns it appears the electron temperature maxima (hot spots) near the hole and slot of outer shell. This is the result of the matter evaporations into the holes. The plasma density is bigger than a critical one in these region, as a result, laser beam does not come into a cavity. **Fig. 2** shows the electron isothermes (the moment of maximum compression was $t_c=2.3$ ns). Such “screen”- effect decreased the efficiency of the targets.

The mass and energy in the region $r \geq R_4$ (see **Fig. 3**) were simulated. as a result it is possible to estimate the losses of mass and energy through the holes. To the end of laser pulse, about 50% of energy contained in the outer shell and expanded plasma. The mass of outer region is decreased as a result of the evaporation from inner side of outer shell.

3. The input of the laser beam into a cavity through the hole

In the following calculation series, possible experiments for the study of the efficiency of laser input into a cavity were simulated in the case of a laser beams with a wavelength of $0.353 \mu\text{m}$ and an energy of 3 kJ. (In [10,11] the experiments were published, researching the input of iodine laser beam through the holes with pulse energy about 10 J).

The simulations were carried out usind 2D cylindrical code NUTCY. The laser flux is $q_L(L, r, t) = q_1(t) * q_2(r)$; q_1 has a right-angled triangular shape with a duration (at the base) of 1 ns, $q_2(r) = \exp(-(r/R_f)^2)/C_1$. Here $R_f=250 \mu\text{m}$, C_1 is the normalization parameter.

The cylindrical cavity is sealed by a low-density absorber ($\rho=2 \text{ mg/cm}^3$).

Fig. 4 shows the shapes of the target and laser pulse. Three regions were murked: the first region (I): $0 \leq z < Z_1^b=400 \mu\text{m}$; the second region (II): $Z_1^b \leq z \leq Z_2^b = 2000 \mu\text{m}$; the third region (III): $Z_2^b < z \leq 3000 \mu\text{m}$. Z_1^b and Z_2^b are the inner boundaries of CH-layers, wich has initial density of 1 g/cm^3 and thickness is $\Delta=70 \mu\text{m}$. r_d - is the radius of hole. It is varied in the simulations. The simulations for the cases $r_d = 200$ (1), 300 (2), 400 (3), 500 (4) and 1000

(5) μm are made. In the case 2 it is about 23% of incident laser flux from without of hole, in the case 3 is about 8% of one.

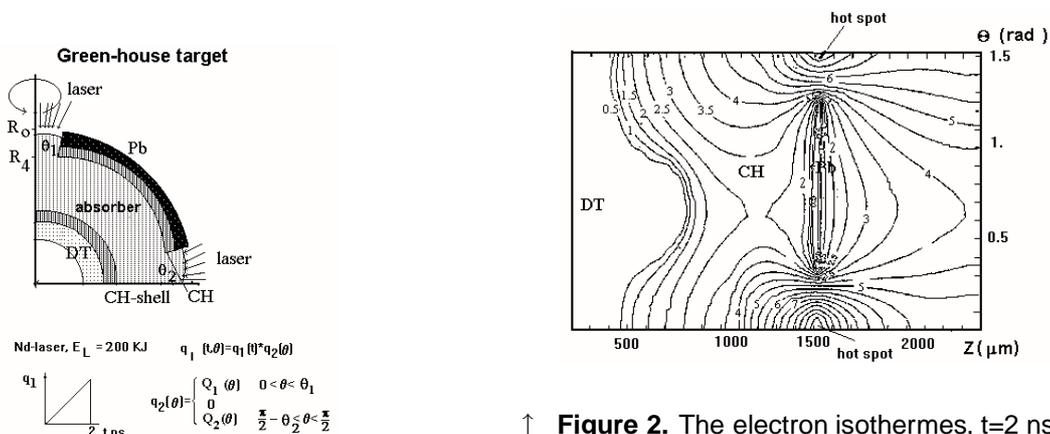
Fig. 5a,b illustrates the pressure, temperature and density distributions along 0Z-axis ($r=0$) at the moment $t=1$ ns for the cases 2 (a) and 5 (b). In case (2) the density of the plasma into the hole is higher than critical one. This is the result of matter evaporation from the wall of the hole. The laser beam is absorbed far from inner layer and as a result the input energy in the cavity (E_{in}) and hydrodynamic efficiency (η) less then ones in the case (5). **Fig. 6** shows the parameters E_{in} and η as functions of the time for the cases 2,3 and 5. The input energy E_{in} is equal the sum of ones in region I and II, hydrodynamic efficiency $\eta=E_I/E_{in}$. The losses of energy are 43% in the case 2, and 13% in case 3.

4. Conclusion

The choice of the suitable sizes of the holes for the Green-house target is a rather difficult problem: increasing the radius of hole leads to increase the hydrodynamic efficiency, but decrease in the thermal smoothing effect. For the considered situation the optimal radius of the hole is about 400 μm .

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↑ **Figure 2.** The electron isothermes, $t=2$ ns.

← **Figure 1.** The task of numerical simulation using FAKEL-code.

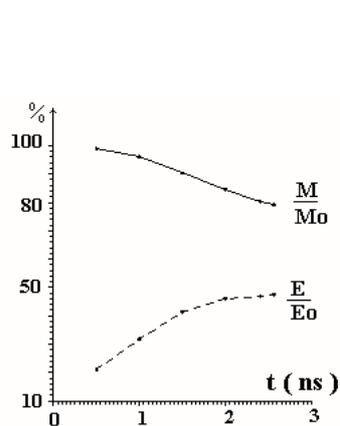


Figure 3. Energy and mass losses as function of time.

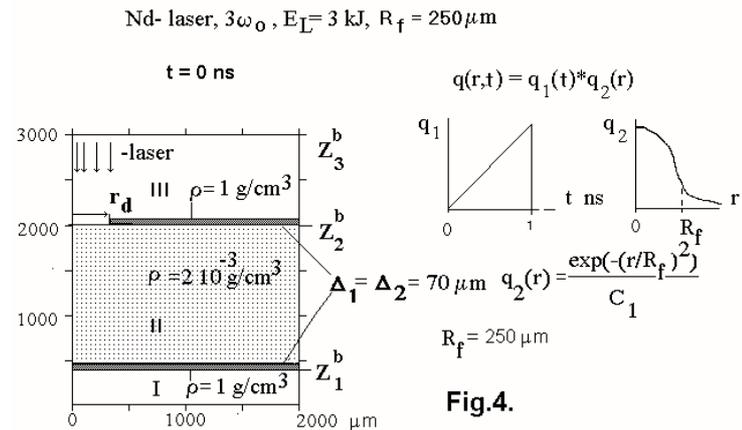


Figure 4. The task of simulations using NUTCY-code.

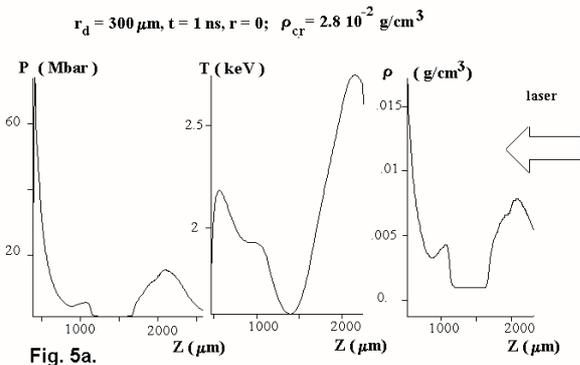


Fig. 5a.

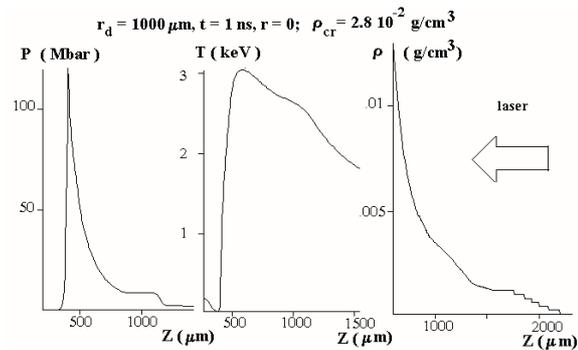


Fig.5b.

Figure 5. Pressure, temperature and density distributions along 0Z-axis at $t=1$ ns for the variant 2 (a) and 5 (b)

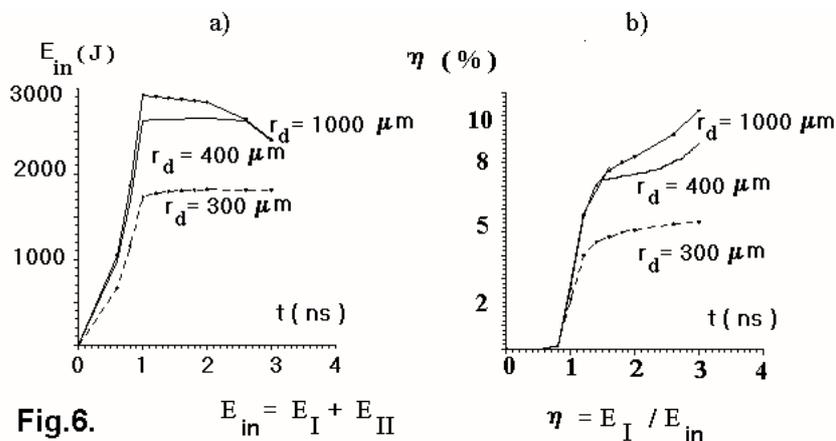


Fig.6.

$$E_{in} = E_I + E_{II}$$

$$\eta = E_I / E_{in}$$

Figure 6. Input energy (a) and hydrodynamic efficiency (b) as functions of time for the variants 2,3,5