Two-dimensional effects in laser compression of glass shells

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Results are presented of two-dimensional calculations of experimentally investigated laser-radiation-compressed glass shells. The effect of various types of initial perturbations on the compression dynamics and on the target–plasma parameters are discussed.

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1. The compression of thin-wall glass shells, both empty and gas-filled, is presently under intensive investigation both theoretically[1] and experimentally.[2] Of great importance in the general problem of laser fusion is the question of hydrodynamic stability of the compression process, particularly the possibility of its study at the present experimental state of the art. There are a number of theoretical-calculation papers in which the stability problem is considered for the high laser energies (10^6 J) and the high degrees of compression needed to attain an appreciable thermonuclear yield.[3]

We discuss here the results of two-dimensional calculations aimed at determining the influence of various types of perturbations in the initial condition on the stability of compression of glass-shell targets with parameters corresponding to the experiments in[2].

2. We solve a system of equations describing axisymmetric hydrodynamic flows with electronic conductivity. Provisions are made for introducing the equation of state of the matter with allowance for "cold" compression, electron-degeneracy effects, nonequilibrium ionization, allowance for electron-ion relaxation, and several other physical effects.

The numerical-solution procedure is based in divergent difference schemes that permit the main conservation laws that hold for systems of differential equations to be unextended to include their discrete analogs.[4] The use of curvilinear grids with conservation of one of the families Lagrangian lines makes it possible to trace the development of the instabilities of the boundaries up to the nonlinear flow stage.

3. The main purpose of the calculations is to assess the effect of initial perturbations of various types on the plasma parameters of the target in the final compression stage for the two-dimensional case. We considered perturbations of two types: deviations from the homogeneity of the flux in the form

$$q(t,\theta) = q_0(t)(1 + a \sin n\theta) \tag{1}$$

and variations of the shape of the shell at the initial instant of time

$$R(\theta) = R_0\left(1 + \frac{\Delta_0}{R_0} \sin n\theta\right). \tag{2}$$

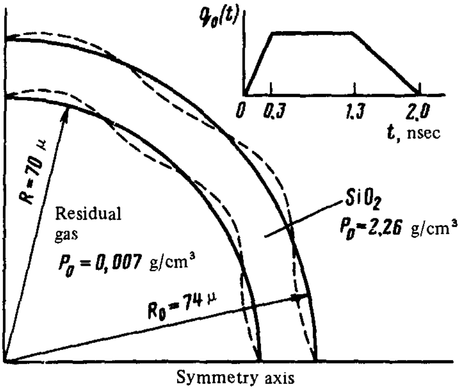

FIG. 1.

Here θ is the azimuthal angle reckoned from the symmetry axis, $q_0(t)$ is the unperturbed radiation flux, a is the relative amplitude of the perturbation of the flux, R_0 is the initial radius of the shell, Δ_0 is the amplitude of the shape perturbation, and n is the number of the harmonic.

The initial parameters of the target and of the laser pulse were taken to be the parameters of the experimentally investigated targets (target mass $\sim 10^{-7}$ g, laser energy $\lesssim 100$ J)[2] (see Fig. 1). We varied the number of the amplitude ($n = 2, 6, 10$) and the amplitude of the perturbation (from a fraction of one percent to several percent).

4. It is known[4] that at least two stages of Rayleigh-Taylor instability set in during the acceleration and compression of the shell,[6] viz., during the time of acceleration of the unevaporated part of the shell by the low-density "corona" and during the deceleration of the cold "remnants" of the shell by the compression-heated center. As already noted in[3], a significant role can be played by the equalization of the perturbation by heat conduction during all stages of the

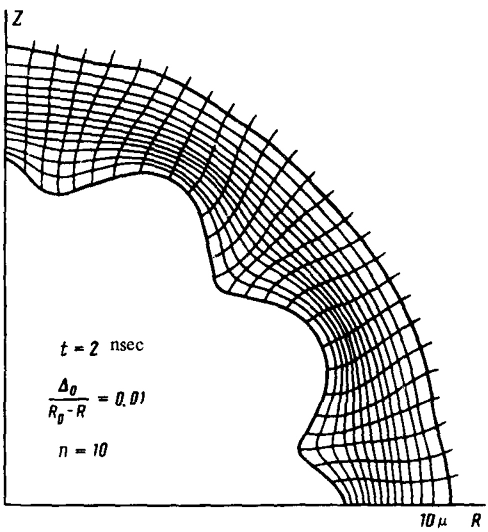

FIG. 2. Shape perturbation.

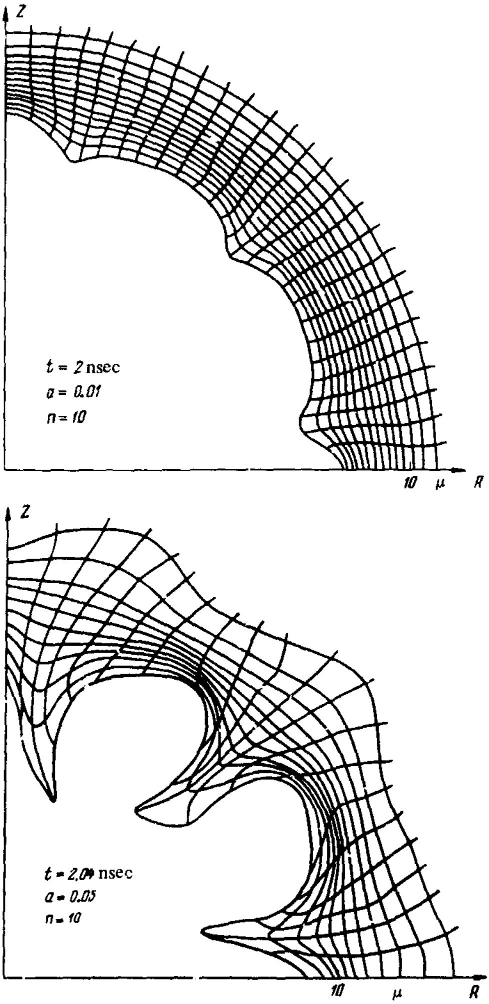

FIG. 3. Flow perturbations.

compressions, provided, of course, that the temperatures are high enough. The average plasma parameters of the plasma are the following: electron temperature in the "corona" 0.6–1 keV, density in the compressed core ~ 5 g/cm^3, density in the cold part of the shell ≤ 200 g/cm^3, and ion temperature at the center of the target ~ 0.5 keV.

An analysis of the results has demonstrated the following. The perturbations develop more slowly during the acceleration stage than during the deceleration of the medium near the center at all the considered perturbation amplitudes (up to 5%). It is typical that the flow perturbations lead to lower amplitudes during the final stage than shape perturbations of the same relative magnitude, thus indicating an equalization by heat conduction (see Figs. 2 and 3). This equalization, however, is much weaker than noted in[3], so that flow perturbations of even small amplitude (1—5%) lead to a distortion of the shape of the shell. A decrease of the heat-conduction equalization can equally be noted during the final stage. The reason for these facts are that the plasma temperature in the considered problems is much lower than in[3] both in the case of the "corona" and in the compressed core.

We note that no-Rayleigh-Taylor growth of perturbations should be observed during the stage of the free flight of the shell (after the acceleration but prior to the deceleration), since the motion is stable; the relative amplitude of the perturbation increases just the same. To explain this effect we can assume that the neighboring sections of the spherical surface do not interact with one another, i.e., they move in the manner that follows from the one-dimensional calculation. The increase of the surface-perturbation amplitude can then be calculated by starting from the initial conditions (the difference between the velocities or masses of the neighboring sections) and the results of the one-dimensional calculation. An estimate obtained by this procedure agrees well with the results of a two-dimensional calculation.

The perturbations develop most strongly during the final stage of the deceleration (see Fig. 3). A change from the linear phase of the perturbation growth to a nonlinear one is noticeable; one can speak of a start of jet formation (see Figs. 2 and 3). This circumstance can be observed both for flow perturbations and for large-amplitude (5%) shape perturbations. In the considered range of amplitudes and harmonic numbers of the perturbations, however, the deviation of the volume-averaged plasma parameters from those obtained in one-dimensional calculations remains insignificant. Thus, it appears that the effect of perturbations of amplitude less than 5% cannot be observed by means of integral measurements, say by pin-point-camera photography. Perturbations larger than 10% can lead to an appreciable deviation of the final shape of the target from a sphere. In this case the results of a two-dimensional calculation can be used to predict the integral picture of the x-ray emission and to compare it with the appropriate experimental data.

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