# Compression of two-layer targets with gaseous DT and neon at the PROGRESS installation

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(Submitted 3 June 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 2, 71–74 (25 July 1986)

The stability of the compression of jacketed glass targets with an aluminum layer on the outer surface, filled with gaseous DT with a Ne admixture, has been studied in experiments on the high-power six-channel PROGRESS laser installation. Images of the laser plasma in x-ray lines of multiply charged aluminum, silicon, and neon ions and also in the x-ray continuum are compared. The data from the x-ray measurements, combined with measurements of the absorbed energy in the neutron yield, are compared with the results of gas-dynamics calculations by the Zarya program.

Although the stability of the compression of jacketed laser targets is one of the central problems in the entire laser fusion program,[1,2] only a limited amount of experimental information is available. The stability of the interface between the aluminum and glass layers of the jacket of a target was studied in Refs. 3 and 4 at an incident power density $q \sim (1-4)\times 10^{16}$ W/cm$^2$, at which the inhomogeneities of the laser plasma are smoothed over to a large extent by the electron thermal conductivity. The stability of the motion of the jacket at $q \sim 10^{13}$ W/cm$^2$ was studied in Ref. 5. In the range $q \sim 10^{14}$–$10^{15}$ W/cm$^2$, on the other hand, there has been no comprehensive experimental study of the stability of the compression of jacketed targets; there is indirect evidence that the compression may be either unstable[6,7] or stable.[8,9]

In the present letter we report experiments on the stability of the compression of $SiO_2$ jackets coated with an outer layer of Al and filled with a mixture of gaseous DT and neon. The experiments were carried out on the PROGRESS six-channel neodymium-laser installation[10] at a laser pulse length of 0.2 ns (width at half-maximum) and at a power density $q \simeq 10^{15}$ W/cm$^2$. Table I shows the experimental conditions.

Here $R_0$ is the initial radius of the jacket; $\Delta_1$ and $\Delta_2$ are the thicknesses of the layers of glass and Al, respectively; $p_1$ and $p_2$ are the initial pressures of the gaseous DT and the neon; $\eta_0$ is the variation in the jacket thickness; $E_t$ is the energy of the laser radiation incident on the target; and $\Delta\overline{E}_c/\overline{E}_c$ is the mean scatter in the energy along the laser channels. The laser radiation is focused to a spot $\lesssim 20\,\mu$m at a distance $L$ behind the target. The parameter $K$ is a measure of the extent to which the input energy entering the channels of the laser apparatus exceeds the level at which a significant self-focusing of the laser radiation would occur in the channels. The variation in the times at which the beams are incident on the target is no worse than 30 ps; the power contrast of the laser radiation in a given series is[11] $\simeq 10^8$.

Table II shows the measured parameters of the laser plasma.

  

TABLE I.

| Experiment | $R_0$ μm | $\Delta_1$ μm | $\Delta_2$ μm | $\eta_0$ | $p_1$ ata | $p_2$ ata | $E_l$, J | $\frac{\overline{\Delta E}_K}{\overline{E}_K}$ | $L/R_0$ | $K$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 53.9 | 0.63 | 0.6 | ± 4.1 % | 14 | 3.2 | 84 | ± 18 % | 3.0 | 0.8 |
| 2 | 73.5 | 0.62 | 0.55 | ± 4.8 % | 15 | 3.5 | 208 | ± 18 % | 2.2 | 1.7 |
| 3 | 74.5 | 0.66 | 0.61 | ± 4.2 % | 14.2 | 3.8 | 155 | ± 9 % | 2.2 | 1.3 |
| 4 | 58.9 | 0.61 | 0.45 | ± 4.9 % | 14 | 2.9 | 188 | ± 18 % | 2.7 | 1.6 |
| 5 | 63.1 | 0.97 | 0.12 | ± 4.9 % | 27.4 | 3.8 | 106 | ± 15 % | 2.5 | 0.6 |

The energy absorbed by the target, $E_a$, is measured by seven plasma calorimeters and three ion collectors, distributed uniformly in terms of direction from the target. The neutron yield $N_{DT}$ is measured by a method of delayed detection by a scintillation detector. The density ($\rho$) of the compressed gas is determined[1)] from the one-dimensional image of the compressed gas in the $Ly_\beta$ line of the hydrogen-like neon ion, with allowance for the resolution of the measurement apparatus. The electron temperature $T_e$ in the compressed gas is estimated from the ratio of the intensities of resonant lines of the hydrogen-like and helium-like neon ions, with allowance for their absorption in the compressed gas and the jacket of the target. Table II shows the values of $\rho'$, the density of the compressed gas found from measurements of the spectral half-width of the line $Ly_\beta Ne^{+9}$, and compares these results with the results of numerical calculations of the Stark and Doppler broadenings of the lines,[13] with allowance for the actual composition of the gas mixture and the measured electron temperature. In the determination of $\rho'$, corresponding corrections were made for the size of the source of the x-ray emission, instrumental broadening, and the self-absorption of the x radiation, by analogy with Ref. 14.

The stability of the compression of the targets is estimated from a comparison of

TABLE II.

| Experiment | $E_p$, J | $N_{DT}$ | $\rho$, g/cm³ | $\rho$, g/cm³ | $T_e$, keV |
|---|---|---|---|---|---|
| 1 | 20 ± 5 | $6 \cdot 10^4$ | – | ≃ 0.2 | – |
| 2 | 55 ± 10 | $2.6 \cdot 10^5$ | – | – | – |
| 3 | 34 ± 7 | $7 \cdot 10^4$ | – | – | – |
| 4 expt | 22 ± 5 | $1.3 \cdot 10^5$ | 0.1 ... 0.2 | ≃ 0.2 | 0.31 ± 0.03 |
| calc | 23.2 | $3.3 \cdot 10^7$ | 0.76 | | 0.72 |
| 5 expt | 20 ± 5 | $1.5 \cdot 10^5$ | 0.4 ... 1 | ≃ 0.3 | 0.30 ± 0.03 |
| calc | 24.9 | $7 \cdot 10^5$ | 0.43 | | 0.38 |

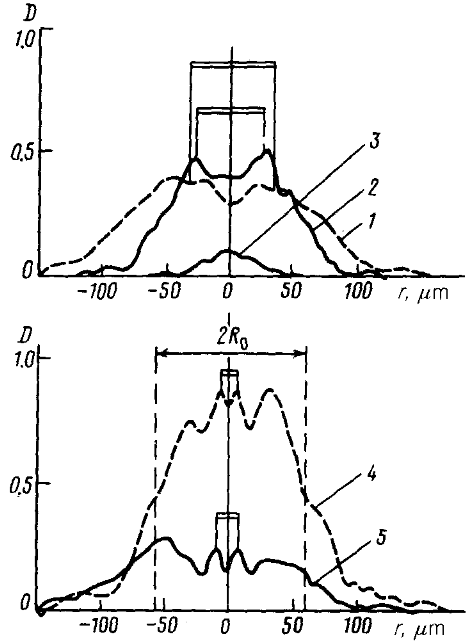


FIG. 1. Densitometer traces of images of the laser plasma in the $Ly_\alpha$ line of $Al^{+12}$ ions (curve 1), in the $w$ line of $Si^{+12}$ ions (2), and in the line $Ly_\beta Ne^{+9}$ (3), along with x-ray pinhole photographs (curves 4 and 5 correspond to average x-ray energies $\bar{\varepsilon} = 2.6$ and 3.5 keV), measured in experiment 4.

the images of the laser plasma in the x-ray lines of aluminum, silicon, and neon ions in various parts of the target and from x-ray pinhole photographs. Figures 1 and 2 show densitometer traces of the images recorded in experiments 4 and 5, respectively. In experiment 4, the x-ray line emission of multiply charged aluminum ions is present at distances $\simeq 35$ $\mu$m from the center of the target, although numerical estimates and calculations by the Zarya program[16] predict that the interface between the aluminum and the glass should approach the center of the target no closer than 53 $\mu$m. At the same time, the size of the compressed region, $2R_{\rm DT} \simeq 40$ $\mu$m, determined from the image in the $Ly_\beta Ne^{+9}$ line, is substantially greater than the diameter of the inner ring on the x-ray pinhole photograph (as shown by the bracketed interval along the horizontal axis in Fig. 1), which corresponds to the x-ray emission of the compressed jacket. All these results are evidence of an instability of both the Al-glass interface and the glass-gas interface in this experiment. This instability may take the form of a deviation of the compression from spherical asymmetry or of a mixing of plasma layers with each other. The fact that the diameter of the inner ring on the plasma image on the line of the silicon ions is slightly greater than $2R_{\rm DT}$ (Fig. 1) can be exploited to estimate an upper limit on the amplitude of the perturbation of the gas-glass interface. Experiments 2 and 3 also show an instability of the Al-glass interface.

In experiments 1 and 5 no emission in x-ray lines of Al is observed from the central parts of the plasma (Fig. 2), implying that the motion of the Al-glass interface is stable in these experiments. The only experiments yielding information on the stability of the gas-glass interface is experiment 5 (images in Ne lines were not recorded in experiment 1). In this experiment, the diameter of the inner ring on the image of the

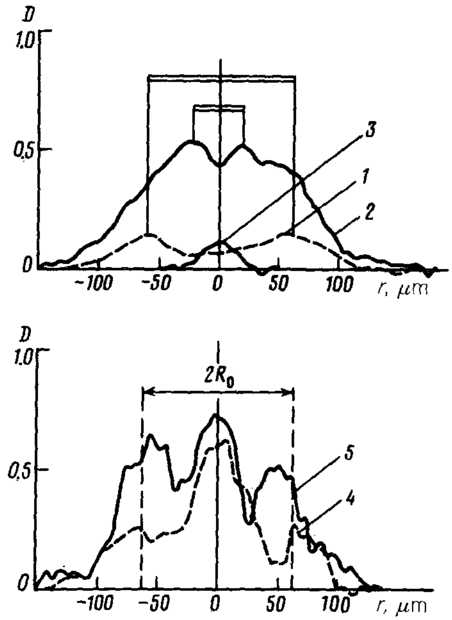


FIG. 2. Densitometer traces of the image of the laser plasma in the $Ly_\alpha$ line of $Al^{+12}$ ions (curve 1), the $w$ line of $Si^{+12}$ (2), and $Ly_\beta Ne^{+9}$ (3), along with x-ray pinhole photographs (curves 4 and 5 correspond to average x-ray energies $\bar{\epsilon} = 1.3$ and 2.6 keV), measured in experiment 5.

plasma in the Si line is substantially greater than $2R_{DT}$, and the absence of a clearly defined ring structure for the central peak on the x-ray pinhole photographs is attributed[2)] to a contribution of the x-ray emission of neon ions at the center of the plasma image. This result strongly suggests that the compression of the gas-glass interface is stable.

As can be seen from Table I, these experiments are characterized by nearly equal values of $\eta_0$, $R_0/\Delta$, $\Delta\bar{E}_c/\bar{E}_c$ and $L/R_0$, which characterize the initial perturbations of the jacket itself and its radiation conditions; in addition, we see identical levels of tautochromism. The only substantial differences are in the values of $K$. We observe a direct correlation between the stability of the compression of the jacket and the value of $K$; when this parameter exceeds unity, we begin to see an unstable compression. This result suggests a possible reason for the unstable compression in experiments 2, 3, and 4: a degradation of the asymmetry of the irradiation of the target because of a deformation of the temporal and spatial profiles of the laser pulse which results from the onset of a fine-scale self-focusing of the beams in the laser amplifier stages. In experiments 1 and 5 this effect is not seen, since the laser energy in those experiments was below the threshold for self-focusing.

The perturbations caused by the self-focusing of the laser beam are the most dangerous since their typical wavelength is on the order of the thickness of the jacket which is being compressed (according to the numerical calculations by the Zarya program, the jacket swells to a thickness $\sim 10\ \mu m$ because of the heating by fast electrons). These perturbations have the maximum growth rate, and they cause the earliest destruction of the jacket in the nonlinear stage of their evolution.[15]

Table II shows the parameters calculated for the laser plasma by the Zarya program for the conditions of experiments 4 and 5, which yielded the greatest amount of experimental information, and in which we observed both a stable compression (experiment 5) and an unstable compression (4). The substantial difference between the calculated and experimental values of the plasma parameters in experiment 4, contrasted with the approximate agreement of calculation and experiment in experiment 5, supports the conclusion reached earlier regarding the nature of the compression of the targets in these experiments.

[1)]Images of the plasma in x-ray lines of the silicon, aluminum, and neon ions were recorded with the help of a spectrograph using plane crystals of gypsum and CsAP with a slit scanning.[12] The images in the silicon and aluminum lines are two-dimensional, since the spectral broadening of these lines is substantially less than that of the neon lines.

[2)]Estimates based on the experimental parameters of the compressed gas put the contribution to the central peak from the x-ray emission of ions at a level comparable to the contribution from the material of the compressed jacket.


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Translated by Dave Parsons