Compression of DT-gas-filled glass shells by a tailored laser pulse

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The effect of a tailoring of the laser pulse used for the heating on the compression of glass shell targets filled with gaseous DT has been studied experimentally at the Progress six-beam laser installation. The DT gas can be compressed beyond the point attainable with a Gaussian pulse.

Achieving a high compression of the DT fuel is one of the central problems in laser controlled fusion. Nuckolls *et al.*[1] have suggested tailoring the temporal profile of the laser pulse to achieve a high compression of solid DT targets. That idea, however, has not been tested experimentally, since the use of shell targets filled with gaseous DT has made it possible to achieve high densities even with pulsese of a simple (Gaussian) shape. Nevertheless, it follows from the calculations of Refs. 2 and 3 that even in the case of shell targets the compression of the DT gas can be increased by a factor of 10–50 by tailoring the pulse.

In this letter we are reporting the first experimental study of the compression of glass shells filled with gaseous DT by a tailored laser pulse. The experiments were carried out at the Progress six-beam Nd laser installation[4,5] at a power density $q \approx 10^{15}$

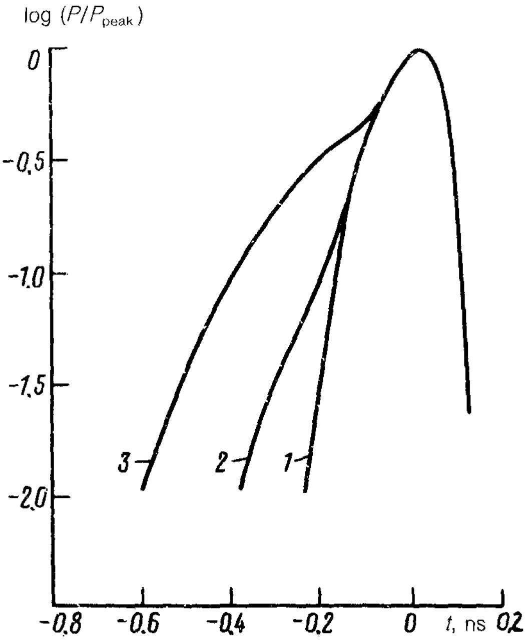

FIG. 1. Temporal profiles of the laser pulses.

W/cm^2 of the heating light. Two groups of targets were bombarded: (1) 80–100 μm in diameter; (2) 150–160 μm in diameter. The thickness of the shells was 0.5–0.7 μm, and the thickness variations were $\lesssim 4\%$. The targets were filled with DT gas to a pressure of 10–25 atm. To most of the targets we added Ne, at a pressure of 2–3.5 atm, for diagnostic purposes.

The pulses were tailored by means of electrooptic deflectors.[4] The particular parameter values of the pulses were selected on the basis of results calculated by the Zarya program.[2] The pulses which we used ($\lambda = 1.06\,\mu$m)) were of uniform length at the half-maximum level: 0.2 ns. The Gaussian pulse had the same length (curve 1 in Fig. 1). Gaussian pulses were also used to bombard both groups of targets. The targets of the first group were bombarded by a pulse with a rise time $\tau = 0.4$ ns at the 0.01 maximum level (curve 2); the corresponding rise time for the second group was $\tau = 0.6$ ns (curve 3). The power contrast of the pulses was 10^8 at a point 1 ns before the maximum. In these experiments we used the method proposed in Ref. 6 for improving the uniformity of the bombardment of the targets, by using phase plates to smooth the beams. Each of the six beams, 110 mm in diameter, was broken up by regular phase plates[7] into ~ 600 elementary square beams, each with a phase shift of π with respect to the neighboring elementary square beams, before focusing onto the target by means of $f/1.5$ objectives. The beams were focused to a point $\sim 2.5 R_t$ (R_t is the target radius) beyond the center of the target.

The energy absorbed by the target was measured by means of seven plasma calorimeters. The absorption coefficient was 20–30%. We found that the phase plates sharply reduced the fraction of the energy carried off by fast ions, from 30–40% to 10–15%

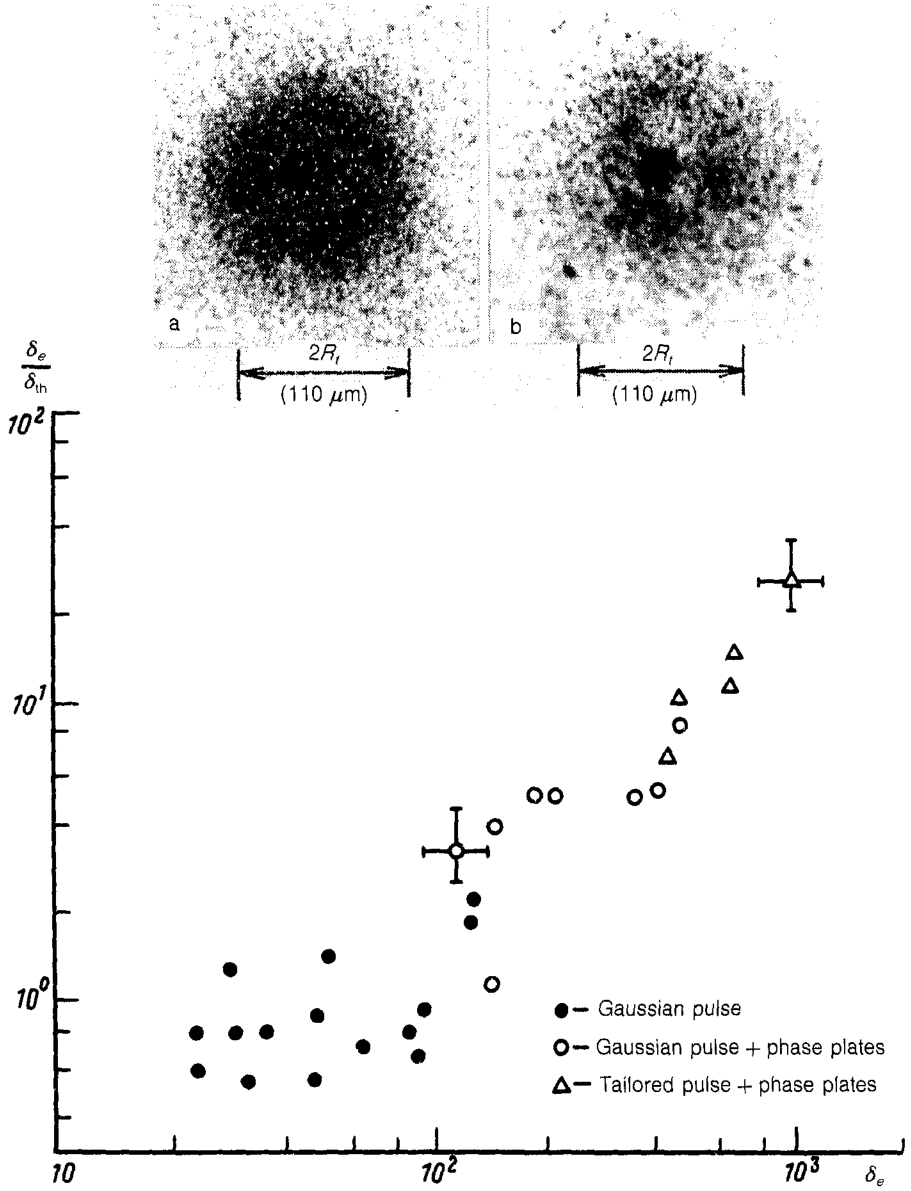

FIG. 2. Comparison of the measured compression δ_e and the theoretical compression δ_t. Shown at the top are x-ray pinhole photographs of targets at an average x-ray energy of 2.6 keV. a—Bombardment with a Gaussian laser pulse; b—with a tailored laser pulse.

at $q \sim 10^{15}$ W/cm^2. Since the energy of the fast ions is proportional to the energy of the fast electrons which are generated by the resonant absorption mechanism, the gas was apparently heated beforehand, to a significant extent, by fast electrons in these experiments (a detailed study of the effect of the phase plates will be published separately).

The volume compression factor was found from x-ray pinhole photographs of the target at average x-ray energies of 1.3 and 2.6 keV (Fig. 2). We took the size of the compressed DT gas formation to be the diameter (d) of the bright central core at half the maximum intensity level. The reason for using d for the evaluation of the compression is that for targets containing NE the pinhole photographs do not have the annular structure of the core which corresponds to the compressed shell at the time of collapse.[1] Further justification for this method for evaluating the compression comes from the approximate equality (within + 15%) of the values of d and the values of the diameter of the bright central ring in experiments in targets without added Ne. Figure 2 compares the measured compression values δ_e with the calculated compression values $\delta_{\rm th} = (M_s/M_g)^{3/2}$, where ($M_s$ and M_g are the masses of the shell and the gas, found on the basis of the model of Ref. 9. In that model the laser pulse is assumed to be a square pulse, and it is also assumed that the gas is initially heated by a shock wave and then subjected to adiabatic compression. Shown for comparison here are data on the compression of targets by a Gaussian pulse without phase plates. We see that the tailored pulse increases δ_e substantially, by an average factor ~4, so that it becomes possible to reach $\delta_e \sim 1500$ [$\delta_e \sim (10\text{–}40)\delta_{\rm th}$]. This result is evidence that the preheating of the gas by the shock wave is reduced, and the compression process is brought closer to an isentropic process. It follows from a comparison of δ_e in the experiments with the Gaussian pulse that the use of the phase plates by itself increases δ_e by an average factor ~4, to ~400 ($\delta_e \sim 4\delta_{\rm th}$), by virtue of the improved unifor-

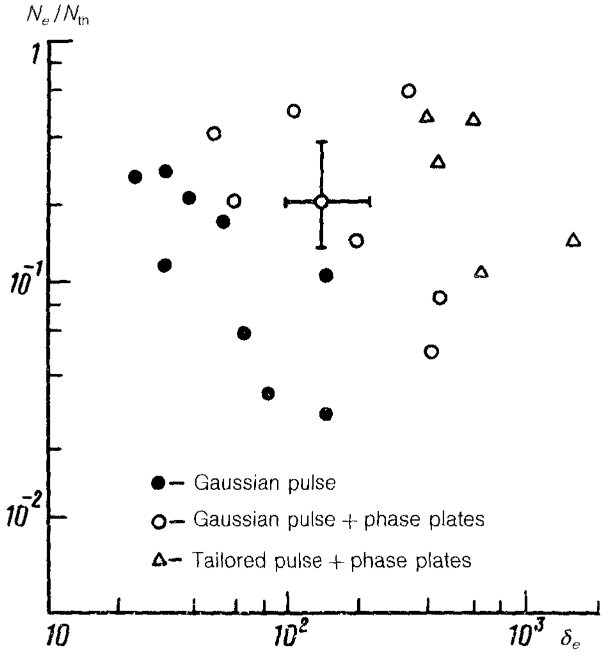

FIG. 3. The normalized neutron yield $N_e/N_{\rm th}$ versus the compression δ_e.

mity of the illumination and the reduction of the gas preheating by fast electrons. Since the conditions of these experiments approach those assumed in the model of Ref. 9, the data found here make it possible to refine the calibration of δ_{th}.

The neutron yield N_e was detected by a method of delayed detection by a scintillation detector. The results of these measurements are shown in Fig. 3, as a plot of N_e/N_{th} versus δ_e, where N_{th} is calculated from the model of Ref. 9. We see that as the compression is increased, the value of N_e moves progressively closer to the calculated value, apparently because of an increase in the effect of the nonuniformity of the illumination on the target compression process. The use of tailored pulses makes it possible to achieve N_e values close to the calculated value at significantly larger values of δ_e, apparently because of an improvement in the stability of the compression in the shell stopping stage, because the shock wave reflected from the center subsequently collides with the moving shell.

In summary, these experimental results confirm the theoretical arguments of Refs. 2 and 3 and demonstrate the promising outlook for further experiments and numerical calculations to optimize the temporal profile of the laser pulse.

[1)] This fact was pointed out previously.[8] According to estimates based on the experimental values of the properties of the compressed gas, the fraction of the central peak, which consists of x-ray emission of neon ions, is comparable to the fraction from the material of the compressed shell.

[1] J. Nuckolls *et al.*, Nature **239**, 23 (1972).
[2] E. N. Avrorin *et al.*, Preprint No. 77, IPM, 1980.
[3] S. Yu. Gus'kov and V. B. Rozanov, Kvant. Elektron. (Moscow) **12**, 410 (1985) [Sov. J. Quantum Electron. **15**, 270 (1985)].
[4] V. N. Alekseev *et al.*, Izv. Akad. Nauk SSSR. Ser. Fiz. **48**, 1447 (1984).
[5] A. E. Barulin *et al.*, Zh. Eksp. Teor. Fiz. **89**, 1575 (1985) [Sov. Phys. JETP **62**, 912 (1985)].
[6] Y. Kato *et al.*, Phys. Rev. Lett. **53**, 1057 (1984).
[7] V. G. Borodin *et al.*, in *Proceedings of the Fifth All-Union Conference on Laser Optics*, 1987, p. 271.
[8] M. G. Anuchin *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **44**, 71 (1986) [JETP Lett. **44**, 88 (1986)].
[9] A. A. Andreev *et al.*, Izv. Akad. Nauk SSSR. Ser. Fiz. **48**, 2270 (1984).

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