Enhanced Laser–Energy Coupling with Small-Spot Distributed Phase Plates (SG5-650) in OMEGA DT Cryogenic Target Implosions

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Cryogenic deuterium–tritium ice target implosions on OMEGA with new small-spot ("SG5-650") distributed phase plates (DPP's) achieved an (11±4)% increase in energy coupling compared to implosions with standard-spot DPP's by decreasing the ratio R of the laser spot diameter to the target diameter from 0.93 to 0.75. The ratio R of the laser spot diameter to target diameter is an important parameter for increasing the hydrodynamic efficiency. A significant increase in hydrodynamic efficiency is expected for smaller R. The hydrodynamic efficiency η is defined as the ratio of the kinetic energy of the imploding shell at the end of the acceleration phase and the laser energy, $\eta = (1/2)mv^2/E_\mathrm{L}$, where m is the mass of the unablated shell (determined from simulations), v is the shell velocity (determined from shell trajectory measurements), and E_L is the laser energy. The SG5-650 DPP's provide a smaller focal spot size of 674 μm, defined as the diameter that encircles 95% of the measured beam energy compared to 834 μm for the SG5-850. The hydrodynamic efficiency, defined as the ratio of the kinetic energy in the imploding shell to the laser energy, increased from 4.5% to 5.0% based on radiation-hydrodynamic calculations benchmarked to shell trajectory and bang-time measurements. Higher energy coupling came at the expense of increased hot-electron production as well as increased hydrodynamic instabilities seeded by a larger mode-10 amplitude from the beam port geometry, both of which may have reduced the fusion neutron production and areal density.

The shell trajectory from a cryogenic DT target implosion was recorded with the technique described in Ref. 1 for a single-picket–pulse implosion. Figure 1(a) shows the measured trajectory (red crosses) of the imploding shell for shot 91837 compared to simulated trajectories from 1-D radiation-hydrodynamic simulations using *LILAC*,[2] assuming the use of SG5-650 DPP's (black curve). *LILAC* includes a 3-D ray-trace model taking the exact shape of the focal spot into account, a nonlocal electron thermal conduction model,[3] a cross-beam energy transfer model,[4] and first-principles equations of state.[5] In addition, the blue curve shows the predicted trajectory as if the experiment had been performed with SG5-850 DPP's. Similar trajectory measurements driven by laser beams equipped with SG5-850 DPP's are in excellent agreement with the calculated trajectory assuming SG5-850 DPP's in a *LILAC* simulation.[6] As expected, the measured shell trajectory in Fig. 1(a) agrees much better with the simulation for $R = 0.75$ (SG5-650) than for $R = 0.9$ (SG5-850). The simulation with the SG5-850 DPP's shows a delayed shell trajectory. Consequently, the shell implodes faster with the SG5-650 DPP, indicating a higher hydrodynamic efficiency η.

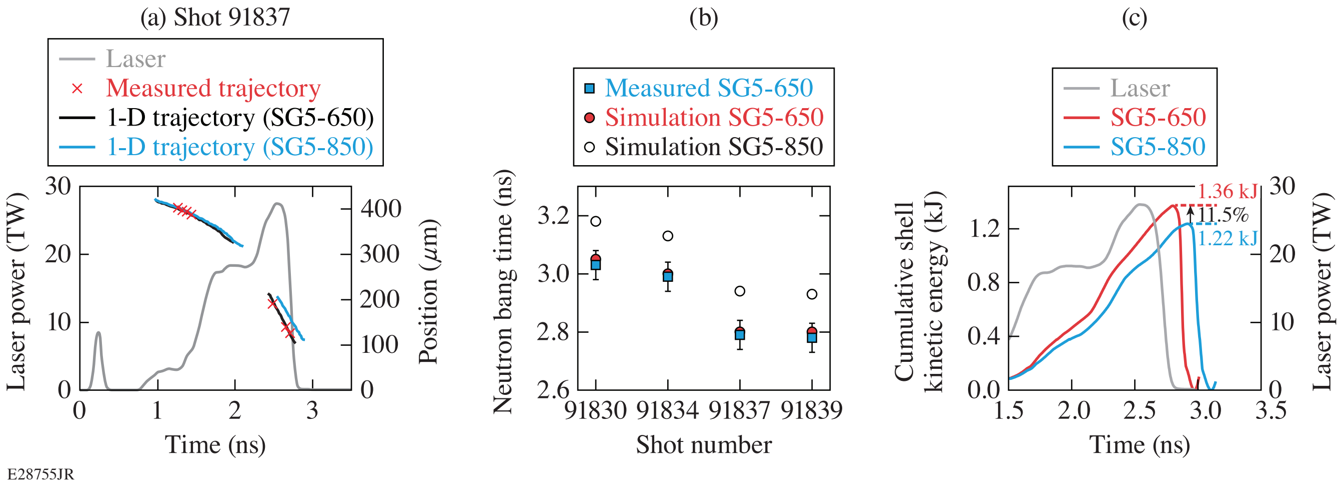

Figure 1
(a) Measured trajectory (red crosses) of the imploding DT cryogenic target shell for shot 91837 in comparison to simulated trajectories assuming SG5-650 DPP's (black curve) and SG5-850 DPP's (blue curve). The gray curve represents the laser pulse. (b) Measured neutron bang time (blue squares) compared to simulated values with SG5-650 (red circles) and SG5-850 (open circles); (c) calculated cumulative shell kinetic energy versus time for shot 91837.

The measured neutron bang time and the absorbed laser-energy fraction support the inferred enhanced energy coupling with SG5-650 DPP's. Figure 1(b) shows the measured neutron bang time (blue squares) compared to simulated values with SG5-650 (red circles) and SG5-850 (open circles). For example, for shot 91837, the measured bang time is 2.79±0.05 ns compared to a predicted bang time of 2.80 ns. Repeating the simulations with SG5-850 DPP's shows that the predicted bang time is later (2.94 ns). The same trend is observed for the other three shots. Knowing that the calculated $(\Delta\eta)_{\text{calc}}$ for shot 91837 is 5.0×10^{-3} and the calculated bang-time shift is 140 ps, the measured bang-time shift of (150±50) ps yields $(\Delta\eta)_{\text{exp}} = (5.5\pm1.8) \times 10^{-3}$. Similar values are obtained for the other three shots since the measured bang-time shifts agree very well with the calculated bang-time shifts. Therefore, the relative increase $(\Delta\eta/\eta)_{\text{exp}}$ is (11±4)% for all four shots and is in agreement with the trajectory measurement and the theoretical value. Figure 1(c) displays the calculated cumulative shell kinetic energy versus time for shot 91837. The energy reaches 1.36 kJ for SG5-650 at bang time and 1.22 kJ for SG5-850; therefore, an 11.5% calculated increase in the kinetic energy of the imploding shell from the smaller-spot DPP. The calculated hydrodynamic efficiency increased from 4.5% with SG5-850 to 5.0% with SG5-650.

Although the experiment provides encouraging results from an increased energy coupling, the overall implosion performance in terms of neutron yield and areal density is poorer compared to other high-performing shots with the SG5-850 DPP's.[6] The smaller DPP focal spots likely limit the implosion performance due to increased hydrodynamic instabilities seeded by low- and mid-mode laser illumination nonuniformity. Three-dimensional hydrodynamic simulations with the code *ASTER*[7] for SG5-650, $R = 0.75$ implosions show a higher susceptibility to low- and mid-mode perturbations induced by target offset, beam mispointing, and power balance compared to similar implosions with SG5-850 and $R = 0.9$. In addition, the beam-port geometry produces, in SG5-650, $R = 0.75$ implosions, a dominant contribution from mid-mode $\ell = 10$.

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