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Polar drive on OMEGA

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Abstract. High-convergence polar-drive experiments are being conducted on OMEGA [T. R. Boehly *et al.*, Opt. Commum. **133**, 495 (1997)] using triple-picket laser pulses. The goal of OMEGA experiments is to validate modeling of oblique laser deposition, heat conduction in the presence of nonradial thermal gradients in the corona, and implosion energetics in the presence of laser–plasma interactions such as crossed-beam energy transfer. Simulated shock velocities near the equator, where the beams are obliquely incident, are within 5% of experimentally inferred values in warm plastic shells, well within the required accuracy for ignition. High, near-one-dimensional areal density is obtained in warm-plastic-shell implosions. Simulated backlit images of the compressing core are in good agreement with measured images. Outstanding questions that will be addressed in the future relate to the role of cross-beam transfer in polar drive irradiation and increasing the energy coupled into the target by decreasing beam obliquity.

Polar drive (PD) [1, 2] enables one to conduct direct-drive experiments while the National Ignition Facility (NIF [3]) is in the x-ray–drive configuration. To achieve nearly symmetric illumination in the absence of beam ports at the equator, higher-latitude beams are repointed toward the equator, compensating for reduced drive. This repointing results in oblique irradiation at the equator. Since laser energy from oblique beams is absorbed at lower densities in the corona, repointing results in reduced hydrodynamic efficiency. The polar-drive NIF ignition design [4] also uses other means to increase laser drive at the equator and achieve adequate symmetry including higher energy for the beams pointed to the equator and specialized laser-spot shapes.

The goal of polar-drive experiments on OMEGA [5] is to validate models used in simulating ignition designs. These include models of oblique laser deposition, any plasma-induced effects such as the energy transfer between laser beams [6], heat conduction to the ablation surface [7], and nonuniformity seeding and growth [8]. Previous PD OMEGA implosion studies [9] used low-adiabat continuous pulse shapes. A relatively low convergence ratio (defined as the ratio of the initial inner shell radius to the inner shell radius at stagnation) of ∼12 was obtained. Recent experiments on OMEGA have used triple-picket laser pulse shapes followed by a square main laser pulse to achieve higher convergence ratios of ∼19, closer to the value of 23 for the ignition design. The triple-picket laser pulse shape is more relevant for ignition since successful compression with a high near-one-dimensional (1-D) areal density of ∼300 mg/cm^2 was obtained in OMEGA triple-picket, deuterium-tritium (DT)–implosion experiments [10].

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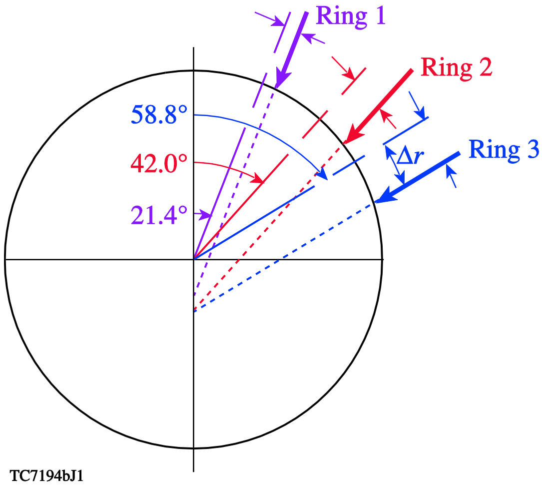

Figure 1. The arrangement of 40 OMEGA beams (the equatorial beams are omitted from the drive) in three rings. Dashed–original beam pointing; dotted–polar-drive configuration, where the beams in each ring are repointed toward the equator along a distance Δr perpendicular to the beam axis.

Triple-picket laser pulse shapes were used to irradiate warm plastic (CH) shells in the PD configuration on OMEGA. Forty of the 60 OMEGA beams, arranged in three rings, irradiated the target. The 20 beams at the equator were omitted from the laser drive. Beams in each ring were repointed by the same distance Δr, defined as perpendicular to the beam axis (Figure 1). Each PD configuration was characterized by three distances, corresponding to the extent of repointing in each of the three rings. Full-beam smoothing was used with $\sim$13.5 kJ of laser energy. The target diameter was nominally 860 μm, corresponding to the 95% energy enclosed diameter of the SG4 phase plates on OMEGA. The laser pulse shapes were based on the low-in-flight-aspect-ratio (IFAR) pulse shapes that previously achieved near-1-D areal densities in plastic shells [11]. The goal was to validate modeling of adiabat, symmetry, and implosion velocity. Cone-in-shell targets were used to infer shock velocities in CH shells using the VISAR (velocity interferometer system for any reflector) diagnostic [12]. Implosion performance, through measurements of areal density using the energy loss of secondary protons [13], neutron-rate timing, and shapes of the compressing core from backlit shell images, is compared with simulations.

A 100-μm-thick CH shell was irradiated with a triple-picket series to measure the shock timing near the equator [Figure 2(a)]. The 40 OMEGA beams arranged in three rings were each repointed toward the equator by 90 μm, 133 μm, and 133 μm respectively. Simulated shock velocities using the hydrodynamic code *DRACO* [8] are shown in Figure 2(b). The simulation uses a full three-dimensional (3-D) ray trace [2] with inverse bremsstrahlung as the mechanism for laser-energy deposition and a flux-limited model (with $f = 0.06$). The simulated shock velocities were approximately 10.8° off the equator, as viewed by the VISAR diagnostic. Shock velocities from the first shock, the catch-up of the second with the first, and the catch-up of the third shock with the first two are visible in the velocity curve. The experimentally inferred values are shown in Figure 2(b). The VISAR diagnostic blanks until the second shock launched by the second picket catches up with the first. The catch-up of the third shock with the first two is visible in the experimentally inferred shock velocities. Simulations reproduce the observed values within the required accuracy of 5% [7], indicating that the adiabat caused by the first three pickets should be well modeled.

Deuterium-filled implosions were performed with the triple-picket pulse shape and a 27-μm thick-CH shell. Approximately 100% of 1-D–predicted areal density of $125 \pm 10\,\mathrm{mg/cm^2}$ was obtained for several shots in the PD configuration. This is nearly twice the areal density obtained in previous PD

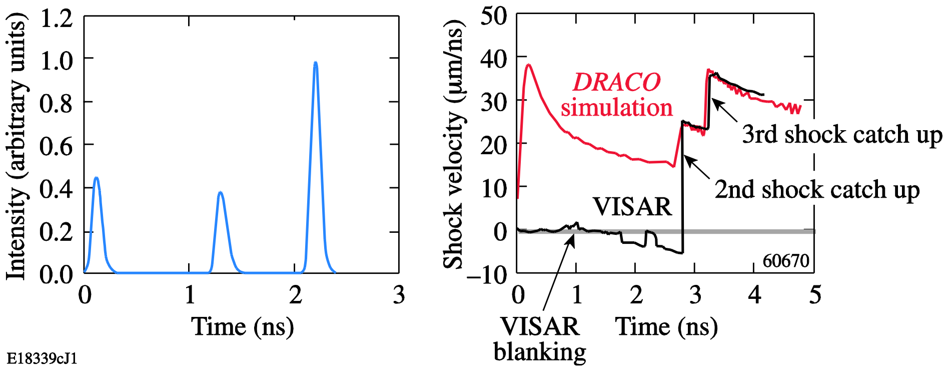

Figure 2. (a) Triple pickets used to irradiate a 100-μm-thick CH cone-in-shell target. (b) Simulated shock-velocity data near the equator (red) compared to measurements (black) for a PD configuration described by 90 μm, 133 μm, and 133 μm.

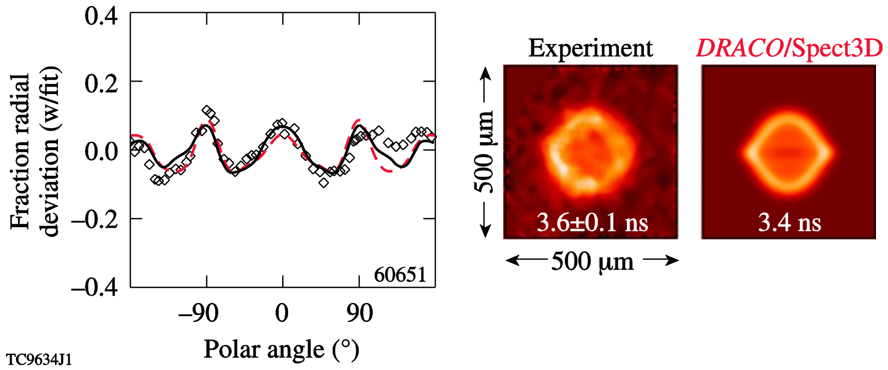

Figure 3. Left: simulated deviation in shell position, defined as the radius of minimum transmission, in the x-ray images versus angle (red) versus measured points (black diamonds) and fit (black line). Middle: Measured backlit image at 3.6 ± 0.1 ns. Right: simulated backlit image at the same mean shell radius corresponding to 3.4 ns.

implosions [9]. This indicates that the adiabat was adequately modeled in the PD configuration. The calculated convergence ratio for these implosions is 19, close to the value of 23 in ignition designs.

Some of the equatorial beams were used to irradiate a Ti foil to produce ~4.7 keV x rays, which were then used to backlight the compressing CH shell [9]. Several different repointed configurations have been studied experimentally. For the implosion shown in Figure 3, the repointed distances for the three rings correspond to 30 μm, 150 μm, and 150 μm respectively. This pointing was chosen since it minimized the $\ell = 2$ mode, where ℓ is the Legendre mode nonuniformity of the compressing shell. *DRACO* simulations were post-processed with the code Spect3D [14] to produce x-ray images obtained through the Ti-backlighting. The radius of minimum transmission is compared between simulations and experiment in Figure 3. Good agreement was obtained between the two. Experimental and simulated images are also shown in Figure 3. Similar shell sizes were obtained between simulation and experiment, but only when a 200-ps delay was introduced in the experimental images. In Figure 3 the simulated images are at 3.4 ns, whereas the experimental images are estimated to be at 3.6 ± 0.1 ns.

The observed bang time is delayed by an average of 180 ± 50 ps relative to simulations in the polar-drive configuration across many shots. This observed delay is independent of the pointing configuration. The error bar represents the error in absolute timing in the neutron-rate measurement and is larger than the standard deviation of the difference between measured and simulated bang times for these shots.

A reduction of approximately 10% in implosion velocity is required in simulations to reproduce measured bang times. A similar reduction in implosion velocity is required to explain bang-time observations in symmetric drive [6, 11]. This loss of drive has been attributed to energy transfer across different laser beams induced by ion-acoustic waves in the plasma [6]. To better model implosion energetics, a cross-beam model is being implemented in the 2-D code *DRACO*. Experiments are planned to measure scattered light around the target chamber to understand the role of cross-beam transfer in the context of oblique beams characteristic of polar drive.

Reducing beam obliquity is also important for increasing implosion velocity. With less-oblique beams, the laser couples at higher plasma densities and consequently increases hydrodynamic efficiency, driving the shell more effectively. To achieve adequate symmetry with less-oblique beams, it is necessary to increase equatorial energies and use custom equatorial laser-spot shapes including an ellipse that preferentially delivers energy to the equator. Work is ongoing to identify these parameters for an optimal low-adiabat OMEGA PD target design that maximizes laser drive while achieving adequate symmetry.

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