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Shock timing on the National Ignition Facility: the first precision tuning series

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Abstract. Ignition implosions on the National Ignition Facility (NIF) [Lindl et al., *Phys. Plasmas* **11**, 339 (2004)] are driven with a very carefully tailored sequence of four shock waves that must be timed to very high precision in order to keep the fuel on a low adiabat. The first series of precision tuning experiments on NIF have been performed. These experiments use optical diagnostics to directly measure the strength and timing of all four shocks inside the hohlraum-driven, cryogenic deuterium-filled capsule interior. The results of these experiments are presented demonstrating a significant decrease in the fuel adiabat over previously un-tuned implosions. The impact of the improved adiabat on fuel compression is confirmed in related deuterium-tritium (DT) layered capsule implosions by measurement of fuel areal density (rR), which show the highest fuel compression ($rR \sim 1.0 \text{ g/cm}^2$) measured to date.

1 Introduction

Indirectly-driven capsule implosions on the National Ignition Facility [1] are driven by a carefully tailored sequence of four shock waves, whose strength and relative timing must be controlled to high precision in order to keep the fuel entropy low and the adiabat close to one.

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Specially modified targets have been designed to allow the velocity history of the shocks to be diagnosed directly inside a liquid-deuterium-filled capsule fielded within a NIF ignition hohlraum. The shock velocity is diagnosed with the Velocity Interferometer System for Any Reflector (VISAR) [2, 3], where the reflector in this case is the leading shock front in the liquid D₂ surrogate fuel. A series of initial experiments were performed to demonstrate the technique on NIF. These experiments delivered a wealth of data, and are described in greater detail in [4, 5]. This paper will focus on the first precision tuning series performed on NIF, which resulted in a significantly decreased adiabat of 1.5 ± 0.1 and an increase in fuel compression by nearly a factor of two. Further details of the present experiments are given in [6].

2 The first NIC precision tuning series

The shocks are generated by a very precise laser-driven power history that consists of a series of step increases in power. Figure 1 shows the laser pulses used for the five shots in the present tuning series. The requested laser pulse shape, shown in black, can only be distinguished from the delivered pulses at the low-power levels following the 1st, 2nd, and 3rd pulses. For all shots, the full 192 beams of NIF were used delivering a total energy within 1% of the request. Throughout the tuning campaign, a number of adjustments were made to the both the timing and levels of the individual pulses.

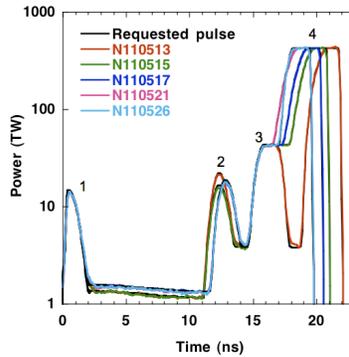


Fig. 1. Laser pulse shapes showing adjustments made throughout the tuning series

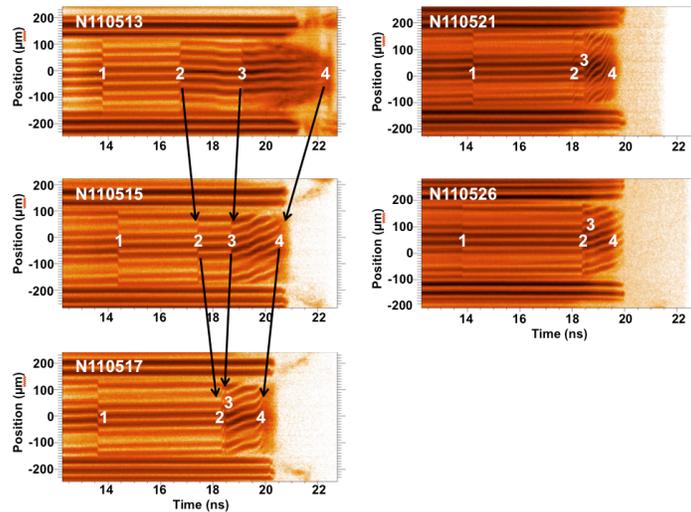


Fig. 2. VISAR streak data for the tuning series showing tuning of shocks 2, 3, and 4

Figure 2 shows VISAR streaked interferometer images for all 5 shots. Time runs from left to right in each image, and lateral (bottom-to-top) motion of the interference fringes is directly proportional to the shock velocity, with fringe motion upward indicating an accelerating shock. The relatively darker fringes at the top and bottom of each image are reflections of the VISAR laser from a stationary Au aperture at the tip of the VISAR viewing cone [4]. Fringe motion between these stationary references is due to reflections from the leading shock front in liquid D₂. Discontinuities in the fringe positions clearly indicate the arrival time of shocks. The first of these, labeled “1” and seen near 14 ns, is the time at which the 1st shock breaks out of the Ge-doped polystyrene (CH) ablator into the liquid D₂. Subsequent discontinuities indicate the time at which the increasingly stronger 2nd, 3rd, and 4th shocks overtake or merge with preceding shocks. As is seen in Figure 2, the interval between successive mergers is initially several ns but is systematically decreased in subsequent shots to approach the goal of having the first three shocks merge at a single time (18.5 ns in Figure 2c) and a single radial location inside the capsule.

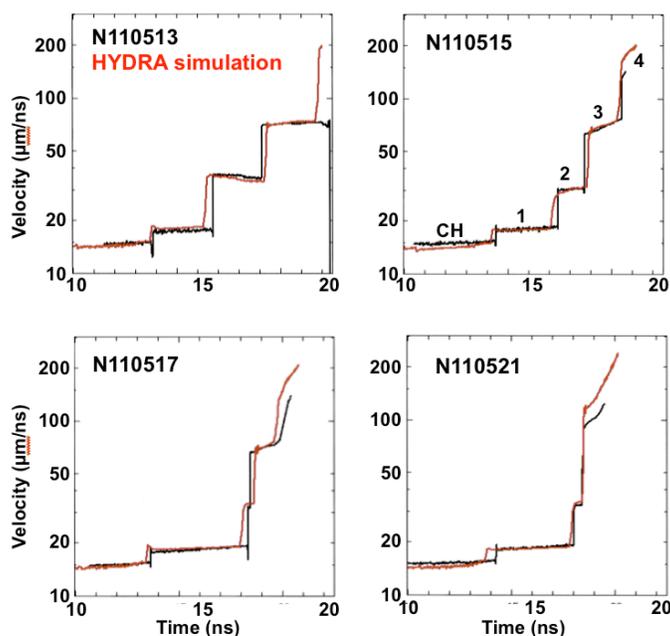


Fig. 3. Comparison of shock velocity histories (black) with post-shot numerical simulation (red)

Figure 3 shows a comparison of the measured VISAR velocity histories with those from post-shot simulations using the radiation hydrodynamics code HYDRA [7]. The VISAR velocity data is shown with the black curves, and the 2-D HYDRA simulations including the measured laser power, measured capsule and hohlraum dimensions, and measured laser backscatter is shown with the red curves. The simulations also account for the effect of cross-beam power transfer between inner and outer cones, which has been found to play a considerable role throughout the laser pulse [8, 4].

Figure 4(a) shows the velocity history for an initially un-tuned pulse with the 3rd and 4th laser pulses delayed by 1 ns each. Figures 4(b, c, d) show the corresponding velocity histories as the laser pulse is adjusted to achieve a coalescence of the first three shocks at the proper radial depth from the inner surface of the ablator (81 μm). The agreement between data and 2-D simulations in Figure 3 is quite good, with the important exception of the 4th shock, which is consistently observed to be ~20% slower than that predicted in simulation. This observation is consistent with ablator shell velocity measurements of [9], where backlit x-ray radiographs of imploding capsules also showed velocities

approximately 15% lower than simulations, but in those experiments the velocity was measured later in time and at much smaller radii (200-400 μm) than the present measurements (700-900 μm).

The fuel entropy and adiabat are not measured directly in these experiments. We estimate the adiabat for an equivalent tritium-hydrogen-deuterium (THD) or deuterium-tritium (DT) implosion [10] using the procedure outline in [4]. The radiation drive in 1-D and 2-D simulations of the shock timing shots are adjusted to match the measured VISAR velocity history to within the experimental error bars. The resulting drive from this procedure is then applied to the as-shot conditions of related THD or DT shots giving an adiabat of 1.4 ± 0.05 from 1-D (spherical) simulations and 1.5 ± 0.1 from 2-D simulations that include the effects of asymmetry as well. A comparison of the improvement in adiabat over the first 6 months of NIC shock tuning experimental campaign is given in Figure 4.

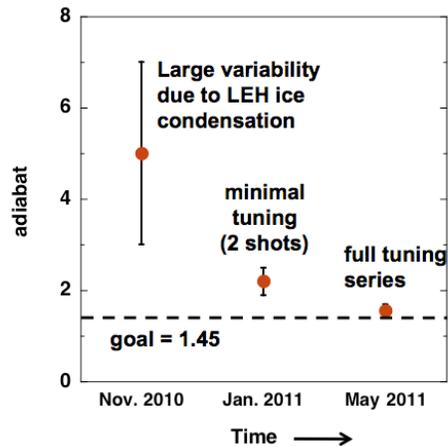


Fig. 4. Adiabat improvements over the first six months of the NIC shock tuning experimental campaign

A confirmation of the improvement in adiabat due to shock tuning is obtained by companion shots [11] employing THD or DT ice fuel layers, which were subsequently shot using the tuned shock timing from the present measurements. In these experiments, the fuel compression is inferred by direct measurement of the ratio of the down-scattered neutron fraction in the 10-12 MeV range over the un-scattered fraction measured from 13-15 MeV. This down-scattered ratio (DSR) is directly proportional to the fuel areal density (ρR). Previous un-tuned shots gave a measured ρR of 0.55 g/cm^2 . Following the present tuning series, four layered capsule implosions using the tuned laser pulse gave ρR measurements of 0.89, 0.90, 0.73, and 0.92 g/cm^2 , nearly a factor-of-two improvement.

References

1. J. D. Lindl *et al.*, Phys. Plasmas **11**, 339 (2004).
2. L. M. Barker and R. E. Hollenbach, J. Appl. Phys. **43**, 4669 (1972).
3. P. M. Celliers *et al.*, Rev. Sci. Instrum. **75**, 4916 (2004).
4. H. F. Robey *et al.*, submitted to Phys. Plasmas (2011).
5. P. M. Celliers *et al.*, EPJ Web of Conferences Proceedings (2011).
6. H. F. Robey *et al.*, submitted to Phys. Rev. Lett. (2011).
7. M. M. Marinak *et al.*, Phys. Plasmas **8**, 2275 (2001).
8. P. Michel *et al.*, Phys. Rev. Lett. **102**, 025004 (2009).
9. D. G. Hicks *et al.*, Phys. Plasmas **17**, 102703 (2010).
10. M. J. Edwards *et al.*, Phys. Plasmas **18**, 051003 (2011).
11. A. J. Mackinnon *et al.*, submitted to Phys. Rev. Lett. (2011).