Sensitivity of Capsule Implosion Symmetry due to Laser Beam Imbalance in a Scale 0.2 Hot Hohlraum at OMEGA

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Abstract: Results are shown from recent experiments at the Omega laser facility, using 40 Omega beams driving the hohlraum with 3 cones from each side and up to 19.5 kJ of laser energy. Beam phasing is achieved by decreasing the energy separately in each of the three cones, by 3 kJ, for a total drive energy of 16.5 kJ. This results in a more asymmetric drive, which will vary the shape of the imploded symmetry capsule core from round to oblate or prolate in a systematic and controlled manner. These results show the sensitivity of capsule implosion symmetry for implosions in “high temperature” (275 eV) hohlraums at Omega. Dante measurements confirmed the predicted peak drive temperatures of 275 eV. Implosion core time dependent x-ray images were obtained from framing camera data which show the expected change in symmetry due to beam imbalance and which also agree well with post processed hydro code calculations.

1. Introduction

Symmetry capsules are planned as a diagnostic of implosion symmetry at varying times during the NIF drive[1]. A suitably designed symmetry capsule samples the drive symmetry during the implosion, whose duration varies for symmetry capsules of different shell thickness. Our capsules use Ge-doped plastic shells with shell thickness varying from 25 µm to 55 µm and filled with 36 atm d-3He gas. We present data from Omega experiments using symmetry capsule implosions in vacuum gold hohlraums 1900x1200 µm, and 70% laser entrance hole, which is approximately a 0.2 NIF scale ignition hohlraum and reaches temperatures of 275 eV similar to those during the NIF drive. Implosion core time dependent x-ray images were obtained which show the expected change in symmetry due to beam balance; and also agree well with post-processed 2D Lagrangian rad-hydro code calculations. Limb brightened images were also seen for some of the capsules, also in agreement with calculation. The 0.2 scale hot hohlraum gives measured hohlraum drive temperatures from the Dante diagnostic in excellent agreement with simulation.

2. Hohlraum Energetics

Previously[2], we described the results of this experiment which were related to the proton spectroscopy aspect, where proton spectra is measured from the capsule implosion and related to the measurement of the capsule unablated shell mass for a measurement of the ρ r of the shell. In this paper, we describe how symmetry is varied in the capsule implosion in a controlled manner, which agrees with calculation. The experiment controls the implosion symmetry by varying the relative energies in each of the laser cones. The nominal (maximum) energies are achieved when the 21°, 42° and 59° laser cones each have energies of 490 J/beam, and for the 40 beams into the hohlraum give an energy of about 19.6 kJ. The pointing was optimized to give a round implosion with full energy.
The full energy shots gave peak hohlraum drive temperatures of about 275 eV and round implosions. In order to change the implosion drive symmetry, we reduced systematically the overall energy in each of the cones. For example, with the 59° cone, we applied 300 J/beam and 490 J/beam elsewhere for a total of 16.6 kJ. For the 42° cone, we applied 200 J/beam and 490 J/beam for the other two cones for a total energy of 16.6 kJ. For the 21° cone, we applied 200 J/beam and 490 J/beam for the other cones, giving a total energy of 16.6 kJ. For each configuration we measured the hohlraum drive with Dante and found a temperature drop of about 15 eV with the reduced laser energies.

3. Symmetry measurements

In the experiment, we obtained implosion symmetry data for implosions of the symmetry capsules with shell thicknesses from 25 μm to 55 μm for both full energy and reduced energy configurations. The implosion core x-ray image was observed using framing camera data filtered with 10 μm Be, so that the energy range is about 1-2 keV x-rays. We obtained images on a number of shots, and show here some results using symmetry capsules of shell thickness 25, 35, 45 and 55 μm. Figure 1 gives the x-ray images for full energy and reduced energy in the 21° cone for capsules of 35 μm shell thickness. The corresponding simulated x-ray image from post-processing the hydro calculation is also shown in Figure 1. The simulated images were taken at peak x-ray emission. The agreement in shape and size is good. Note that the implosion core goes from round with full energy to slightly oblate with reduced energy. Also note that a faint limb brightening is seen in both the data and simulations. This is due to the Ge-doping in the CH shell. The limb brightened image aids in the image analysis in determining the accurate shape of the implosion core. The images from both of the reduced energy shots show qualitatively a less round image as can be seen from the square contours in the images which indicate P4 asymmetry. The image shape can be described by the eccentricity, \( e = a/b \), where \( a \) and \( b \) are the major and minor axis diameters. The \( a/b \) from the simulated image is 1.0, 0.86 and 0.96 for the full energy, lower 21 and lower 59° cones. Thus the effect of beam asymmetry is weak but measureable for the 35 μm shell thickness.

Figure 1: comparison of measured and simulated 35 μm capsule implosion x-ray images.

In Figure 2 we show similar comparison of measured and simulated 25 μm thick shell imploded core images. Limb brightening is also apparent for these images and we can
see a slight shape change from full energy shot to reduced energy in the 59° cone. The simulated images have an a/b of 1.08 and 1.0 for the full energy and lower 59° cone shots respectively. The effect of beam imbalance is slight for the 25 µm shell thickness.

Figure 2: comparison of measured and simulated 25 µm capsule implosion x-ray images.

In Figure 3, results from the 45 µm shell implosions with reduced laser energy in the 42 and 59° cones are shown. Both framing camera data at peak emission and post-processed simulations at peak emission are shown. The simulated images have a/b of 0.84 and 0.94 for the lower 42 and lower 59° cone shots respectively. The framing camera data shows more of a symmetry change than calculated. Thus the effect of beam imbalance is significant for the capsules with shell thickness of 45 µm.

Figure 3: comparison of measured and simulated 45 µm capsule implosion x-ray images.

In Figure 4, results from the implosion of the thick 55 µm shell capsules are shown. These capsules generate the higher degree of convergence than the other thinner shell capsules, allowing instability growth to disrupt the symmetry of the implosion. The framing camera data showed a strong asymmetry developing during the implosion with the reduced energy in the 21° cone, and this was also well modeled in the post-processed implosion simulation. Thus the effect of a beam imbalance is significant for the thickest shell targets with 55 µm shell thickness. The thick shell targets in general have the longest implosion times, larger capsule convergence and are subject to turbulent mix and shell breakup during the implosions. Thus these targets would be expected to be most sensitive to the imposed laser beam imbalances.
4. Conclusion

In conclusion, we have shown results from Omega experiments on symmetry in high temperature hohlraums, which are relevant for further NIF experiments. We show good agreement for hohlraum energetics between data and simulation[2]. We show qualitative agreement for implosion symmetry between data and simulation; as indicated by size and shape of the implosion core, so that we can “tune” the shape of the implosion in agreement with modeling simply by varying the energy in each of the laser cones entering the hohlraum. The capsules with 45 and 55 μm shell thickness are especially sensitive to beam imbalance. The effect of beam imbalance on the 25 and 35 μm shell capsules is less dramatic, though measureable.

References:
[1] J.D. Lindl, et.al., Physics of Plasmas, 11, 339-491 (2004).
[2] N. Delamater, D.C. Wilson, G.A. Kyrala, et.al., Rev. Sci. Instr., 79, 10E526 (2008).