Investigation of the effect of the final laser pulse shape on capsule energetics and laser-plasma interactions for ignition targets

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Abstract. We present an evaluation of the effects of a modified final laser pulse on capsule energetics and Laser-Plasma Interactions (LPI) for a National Ignition Facility cryogenic ignition target. A point design laser pulse is well optimized for the capsule and has reasonably good expected LPI performance. However, we demonstrate that reduced exposure to LPI backscatter is possible for an ignition target with a reduction in capsule margin by reducing the laser peak power and slightly re-balancing the beam energy. The benefit of this reduced LPI exposure is expected to be highest if the ignition target LPI exhibits a threshold intensity near the laser pulse peak intensity. In this case, it may be possible to reduce LPI exposure while delivering adequate energy into the hohlraum and achieve adequate symmetry to ignite the capsule.

1. Introduction

The National Ignition Facility (NIF) will be completed in 2009 and is scheduled to begin cryogenic experiments in the summer of 2009. There is a significant effort on-going to optimize the target design for the NIF[1] ignition target. This effort is aimed at optimizing the implosion symmetry and capsule margin while mitigating the effects of laser-plasma interactions on laser coupling and hohlraum energetics. The symmetry of the implosion is dominated by asymmetry in the capsule irradiation due to variation in the x-ray fluence from the hohlraum wall and radiation loss through the laser entrance hole (LEH). The dominate contribution to the expected scattering of laser light in the plasma is less well understood. However, one important parameter is the peak speckle intensity since the Raman and Brillouin instabilities both scale strongly with laser intensity. Due to these optimization and design trade-offs, the ignition target design is rapidly evolving.
Figure 1. Laser pulse peak power and peak intensity for the base case (black) and the case with nominally the same peak power, 10 percent and 25 percent lower peak power. The left figure is the inner cone and the right figure is the outer cone.

One important design parameter is the required radiation temperature in the hohlraum since this temperature affects the size of the hohlraum and capsule. This temperature is affected by the size of the laser entrance hole (LEH) and thus the laser-pulse peak intensity. There have been several different targets designed, which operate at a different radiation temperature in the hohlraum. The current design (June 2007) is driven by a radiation temperature of 285 eV. However, the point design in December 2006[2] was driven at 300 eV and is the target used for this study.

2. Flat Pulse Design
We will focus this study on laser pulses which have identical initial three pulses such that the first three shocks remain identical across the targets. We will also modify the final pulse by using a flat-top peak in the laser pulse. In Figure 1 we show the base case from December 2006 (black) and three flat-top pulses with nominally the same peak power, 10 percent lower power and 25 percent lower power. The peak length of each pulse was increased as the peak power was reduced in order to try and preserve the total energy in the pulse. The left axis in Figure 1 is the laser pulse power. The axis to the right is the laser intensity at the laser focal spot. The growth of LPI can be related directly to the laser pulse intensity per quad of four beams, thus lower intensity corresponds to lower LPI gains. However, recent experiments have demonstrated that there may be a threshold intensity which can make LPI appear to increase rapidly at a critical intensity[3]. Although this threshold is not yet known for the expected conditions on the NIF it is thought to be around $10^{15} \text{W/cm}^2$. From Figure 1 we can see that the outer cone has a peak intensity above $10^{15} \text{W/cm}^2$. In the cases shown in Figure 1 we did not modify the relative beam power between the inner and outer cones, thus the power balance and laser pointing are identical to the base case.

The effect of reduced peak power on the capsule symmetry are shown in Figure 2. Figure 2(a) is the density of the capsule at ignition time for the base case. Notice that this capsule has substantial P4 which was removed by re-pointing the laser pulses in a subsequent design iteration; however, for the purpose of this study the behavior was
Figure 2. Image of density at ignition time for the three cases of interest. (a) is the base ignition design, (b) is for the case with 25 percent lower peak power. (c) is for the case with 2 percent higher peak power in the inner cone and 1 percent less in the outer cone.

adequate to assess the effects of a modified final pulse. Figure 2(b) shows the density at ignition time for the case with 25 percent lower peak power in the cones. Notice that without any re-balancing of the beam power the capsule symmetry has deteriorated and the hot spot appears to be disrupted by islands of higher density. Figure 2(c) shows the positive effect of modifying the beam power balance. In this case the inner cone power was increased by 2 percent and the outer cone was reduced by 1 percent. From Figure 2(c) we can see that it is possible to recover capsule symmetry by simply re-balancing the beam power leaving re-pointing the laser as an additional lever.

The ignition time is delayed with reduced peak power for two reasons. First, the actual total energy in the laser pulses is not exactly the same, the case with 25 percent lower power is 7.5 percent lower energy. Second, the capsule appears to perform better when driven hard early on in the pulse since in the case with nominally the same peak power the energy is still lower by 7.5 percent but the ignition time is earlier than the base case. Additionally the total energy was brought back in line with the base case for the capsule in Figure 2(c) and the ignition time is still later than the base case. The kinetic energy in the fuel shows that the base case has the highest peak kinetic energy while the kinetic energy for each of the flat-pulse cases is lower, including the case with nominally the same peak power. This reduction in fuel kinetic energy in the case with the same peak power but a flat profile is likely due to the sensitivity of the capsule to the detailed drive history. The capsule was designed to maximize margin for the original pulse profile so deviation from this drive history results in reduced fuel kinetic energy and thus margin. As the peak power is reduced the peak in the kinetic energy decreases even with the total laser energy held constant. This indicates that although it is possible to reduced the potential exposure to LPI it comes at a reduced fuel kinetic energy in the capsule. The effect that these changes have on other figures of merit are comparable to the effect on the capsule fuel kinetic energy. For instance, as the peak power is decreased the average fuel $\rho r$ also decreases but re-balancing the beams restores the $\rho r$ to that of the base case. Similar effects are seen for the capsule yield, although all the capsules in this study ignited and gave several MJ of energy.

We can examine the effect the reduced intensity has on LPI by looking at Figure 3. In Figure 3 we see the laser pulse for both the base case and the flat pulse with 20 percent lower peak power (solid lines). We also show the gain exponent calculated using
Figure 3. Solid lines are the laser pulse power per quad for the December 2006 design (black) and for the case of 20 percent lower power (red) with beams re-balanced. The crosses are the gain exponent for SRS backscatter, left axis. Figure (a) is for the inner cone while Figure (b) is for the outer cone.

LIP[4] to calculate the linear growth for Stimulated Raman Scattering (SRS) backscatter (crosses). One thing that is noticeable is that although the peak intensity is down by roughly 20 percent the LPI benefit appears to be only about 10 percent in gain exponent. Additionally, we see that the LPI gain appears to be increasing toward the end of the laser pulse which shows the importance of the plasma conditions on LPI. We see a similar behavior for the Stimulated Brillouin Scattering (SBS) backscatter.

3. Conclusions
We have examined a method for reducing the potential LPI back scatter for a particular NIF ignition target design without modifying the ignition target hardware or capsule. We demonstrated the ability to retune the capsule symmetry by re-balancing the inner and outer cone energy to achieve comparable capsule behavior; however, overall capsule fuel kinetic energy was reduced. This reduction in kinetic energy would result in reduced margin to ignition and thus this technique is not likely a final solution for LPI problems. Further changes to the capsule would likely be required. Although this study was conducted with a particular target design, it is probable that the results are relevant to other potential ignition targets should LPI prove a substantial problem for achieving ignition. This technique would be expected to be most beneficial should an intensity threshold be identified close to the design peak intensity. Then this method could be used to transition below this threshold while maintaining comparable capsule behavior.

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