Direct-driven target implosion in heavy ion fusion

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Abstract. In inertial confinement fusion, the driver beam illumination non-uniformity leads a degradation of fusion energy output. A fuel target alignment error would happen in a fusion reactor; the target alignment error induces heavy ion beam illumination non-uniformity on a target. On the other hand, heavy ion beam accelerator provides a capability to oscillate a beam axis with a high frequency. The wobbling beams may provide a new method to reduce or smooth the beam illumination non-uniformity. First we study the effect of driver irradiation non-uniformity induced by the target alignment error (dz) on the target implosion. We found that dz should be less than about 130 μm for a sufficient fusion energy output. We also optimize the wobbling scheme. The spiral wobbling heavy ion beams would provide a promising scheme to the uniform beam illumination.

1. Introduction

In direct drive inertial fusion [1], lasers or ion beams are used as an energy driver. The ion beam generation and absorption efficiencies are high; heavy ion beam (HIB) deposits its energy inside of the fuel target. HIB has preferable characteristics of the stabile and repetitive operation of HIB accelerator and a precise beam axis control as well as its high efficiency (~30-40%) of HIB generation. Therefore, it is considered that HIB would be a promising candidate of an energy driver in inertial fusion [2-4]. In this study, we employ Pb HIBs as the energy driver beams in order to study a beam illumination non-uniformity onto a spherical target.

In an actual inertial confinement fusion, a fuel target is irradiated by HIBs, when a fuel target is injected and aligned at the center of the fusion reactor [5]. A fuel target alignment error (dz) would appear; the target alignment error induces the HIBs illumination non-uniformity on the target. The beam illumination non-uniformity leads a degradation of fusion energy output.

In this paper, a direct-drive scheme is employed, and we present the HIBs illumination non-uniformity effect on the fuel target implosion. As a result, we found that dz should be less than about 130 μm for a sufficient fusion energy output.

2. Simulation model

Figure 1(a) shows a fuel target in heavy ion inertial fusion (HIF). The target consists of Al and C as a tamper and a HIB-energy absorber, respectively [6-9]. Figure 1(b) shows the input pulse employed. We call the lower power part in the input pulse as the foot pulse and the higher power one as the main pulse. The input Pb beam energy is 1.8MJ. We employ a 32-HIBs illumination system [10]. The HIBs illumination non-uniformity is evaluated by the global *rms*, including also the Bragg peak effect in the
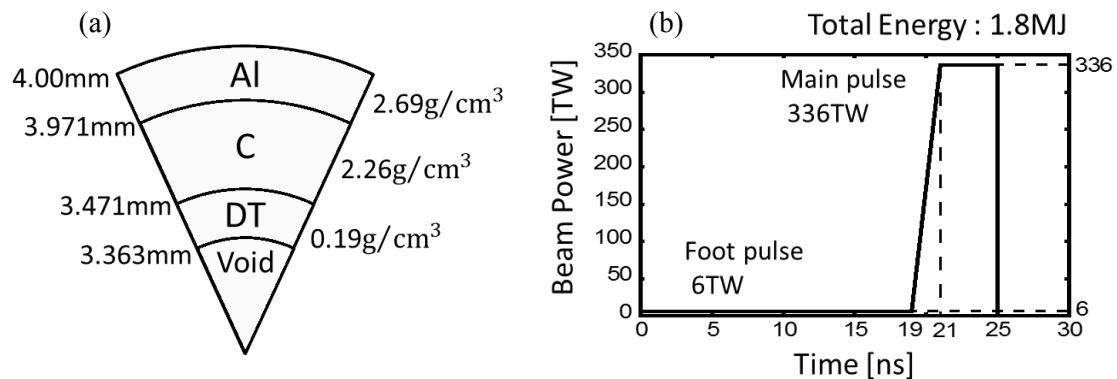
Figure 1. (a) Target structure and (b) The HIB input pulse.

energy deposition profile in the target radial direction. In HIF, the Bragg peak deposition area plays the most important role for the target implosion.

3. HIBs illumination non-uniformity Effect on fuel target implosion

First we show the implosion dynamics in order to verify the effect of the HIBs illumination non-uniformity on the target implosion, when the illumination non-uniformity is 2.87%. The target alignment error dz shows the displacement from the fusion reactor center. The HIBs used in this section are the Gaussian beams, whose radii are 3.3mm. Figures 2 show the mass-density distributions at (a) t=10ns, (b) t=28ns and (c) t=35ns. The HIBs deposit their energy mainly in the C layer by the Bragg Peak characteristic. The density valley appears in the C layer. In Fig. 2(a), the DT layer is accelrated further toward the center. Then, the high-density core is formed at the center of the target immediately after the void close.
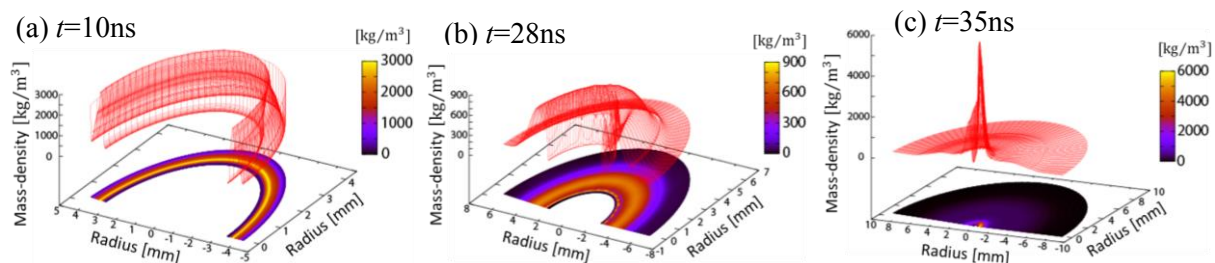

Figure 2. Mass-density distributions at (a) t=10ns, (b) t=28ns and (c) t=35ns.

In this section, we studied the effect of the HIBs illumination non-uniformity on the implosion. Figure 3 shows the fusion energy gain curve versus the target alignment error dz, and also the illumination non-uniformity versus dz. We obtained the relationship between dz and illumination non-uniformity by the precise HIBs illumination code in Ref. [11]. Figure 3 shows that the fuel ignition was not achieved beyond about dz=140μm. The results in Fig. 3 present that the target algnment error dz should be less than about 130 μm for a sufficient fusion energy output.
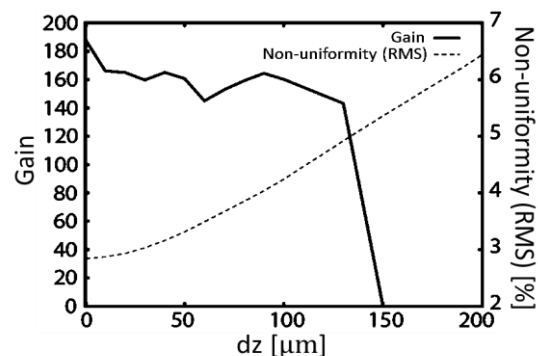

Figure 3. Fusion gain and illumination non-uniformity vs. target alignment error dz.

In order to verify the effect of the illumination non-uniformity, we have analyzed the non-uniformity of the ion temperature in the three cases of dz=0μm, 60μm and dz=150μm. Figure 4 shows the non-uniformities of ion temperature at each time. At the time of 5ns (Fig. 4(a)), the non-uniformity at the Al and C layers increases with the increase in the the target alignment error. As times passes, the effect of the HIBs illumination non-uniformity appears at the target inner part as shown in Figs. 4(b) and (c).
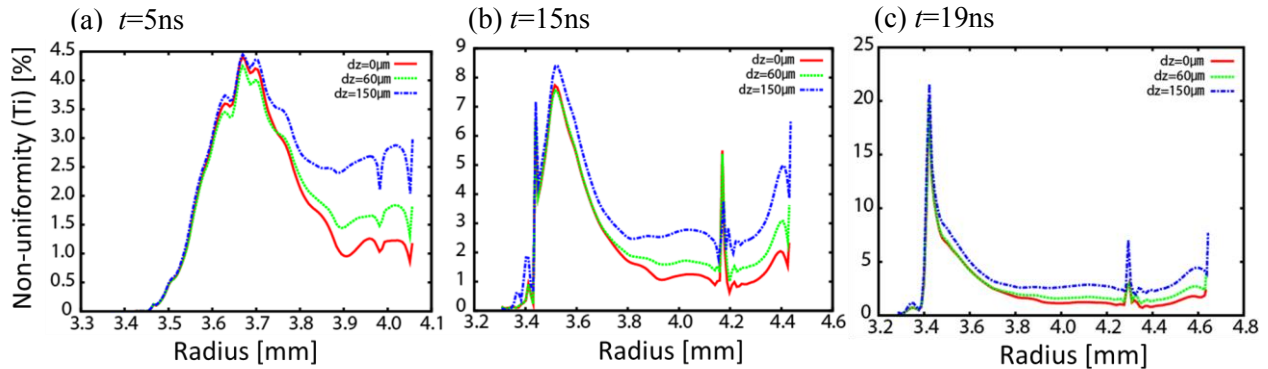

Figure 4. Non-uniformity of the ion temperature in the θ direction at (a) t=5ns, (b) t=15ns and (c) t=19ns.

Figure 5 shows the non-uniformities of the density at 21.8ns for the three cases of dz=0μm, 60μm and dz=150μm. In Fig. 5 the maximum non-uniformity becomes 24.5% for the target alignment error dz=150μm, though the maximum non-uniformity is less than about 20% for the cases of dz=0μm and 60μm. As a result, the fusion gain was not obtained for the target alignment error dz=150μm. However, for the cases of dz=0μm and 60μm a sufficient fusion energy output was obtained as shown in Fig. 3.
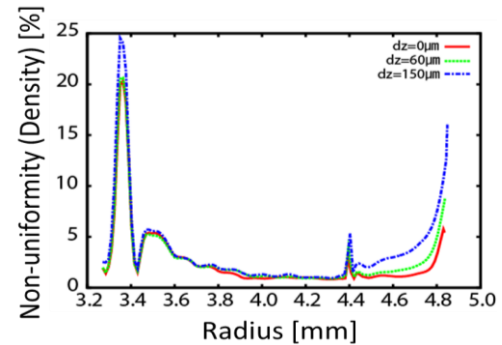

Figure 5. Non-uniformity of the mass-density in the θ direction at t=21.8ns.

4. Spiral wobbling HIBs illumination uniformity on fuel target implosion

In the Section 3 we found that the fuel target gain is quite sensitive to the driver beam illumination uniformity. In order to reduce the HIBs illumination non-uniformity, wobbling HIBs were proposed [12-15]: the HIBs axes are rotated to smooth the illumination non-uniformity. However, it was found
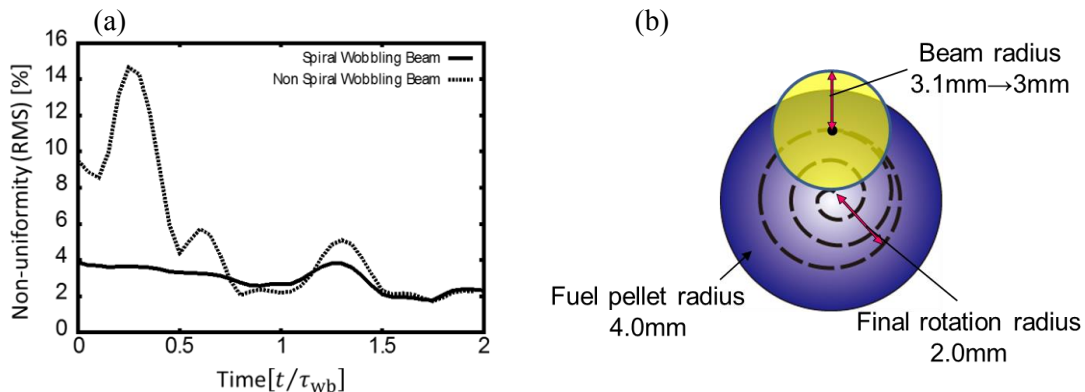

Figure 6. (a) Histories of the illumination non-uniformity and (b) schematic diagram for spiral wobbling beam.

that the simple rotation of the HIB axis introduces an unacceptable initial imprint of the HIBs illumination non-uniformity, as shown in Fig. 6(a) (dotted line).

In this Section, we optimize the wobbling beam illumination. We found that the initial imprint is reduced by the spiral wobbling beams (Fig. 6(b)). Figure 6(a) shows the illumination non-uniformity history during the first few rotations. Here τ_{wb} is the time for one rotation of the wobbling beam axis. The non-spiral wobbling beam has the beam radius of 2.0mm and the beam rotation radius of 3.0mm. For the spiral wobbling beam the beam radius changes from 3.1mm to 3.0mm at $t = 1.3\tau_{wb}$. As shown in Fig. 6(a), the initial imprint of the maximum non-uniformity at the beginning of the irradiation is greatly reduced from 14.7% to 3.56%.

5. Conclusions

In this paper, we present the effect of illumination non-uniformity on the target implosion. The target alignment error in a fusion reactor introduces and increases the HIBs illumination non-uniformity. As the illumination non-uniformity increases, the fusion gain is degraded. We found that *dz* should be less than about 130 μm for a sufficient fusion energy output, and that at *dz*<130μm the HIBs illumination non-uniformity was less than 5% [16]. Toward the further smoothing of the HIBs non-uniformity, we also proposed the spiral wobbling beam illumination; the spiral wobbling heavy ion beams would provide a lower illumination non-uniformity. The further studies are required on the beam illumination non-uniformity smoothing in the near future.

Acknowledgements

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