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Implosion Uniformity of Fuel Target in Heavy Ion Inertial Confinement Fusion
重イオンビーム慣性核融合における燃料標的の爆縮均一性

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The implosion uniformity is studied in inertial confinement fusion based on heavy ion beams (HIB). It is well known that HIBs have a high controllability, a high driver energy conversion efficiency and a high repetition rate. Wobbling HIBs are easily available as the energy driver in inertial fusion. We have found that the wobbling HIBs would reduce the Rayleigh-Taylor instability growth significantly, and then the implosion uniformity is improved well.

1. Introduction

In inertial confinement fusion, the driver beam illumination non-uniformity leads a degradation of fusion energy output. Therefore, it is important to reduce the driver beam illumination non-uniformity [1]. The beam illumination non-uniformity allowed is less than a few percent in inertial fusion target implosion [1, 2]. We study the implosion uniformity in heavy ion beam (HIB) inertial confinement fusion (HIF) in this research.

HIB has preferable features, and the HIB axis is precisely controlled with a high frequency [3]. The energy conversion efficiency of the HIB generation is high, that is, about 30-40%.

2. Wobbling Heavy Ion Beam Illumination

In inertial fusion, the fusion fuel compression is essentially important to reduce an input driver energy, and the implosion uniformity is one of critical issues to compress the fusion fuel stably. Therefore, the Rayleigh-Taylor (R-T) instability stabilization or mitigation [3, 4] is attractive to minimize the fusion fuel mix. In heavy ion inertial fusion (HIF) the HIBs illumination non-uniformity would be mitigated by the wobbling beam motion, that is, the HIB axis oscillation or rotation [3, 4].

Figure 1 shows an example simulation for R-T instability, which has one mode. In this example, two stratified fluids are superposed under an acceleration of $g = g_0 + \delta g$. In this example case the wobbling frequency Ω is $2\pi\gamma$, the amplitude of δg is $0.1 g_0$, and the results shown in Figs. 1 are at t=8γ. The growth rate of the instability is γ. In Fig. 1(a) δg is constant and drives the R-T instability

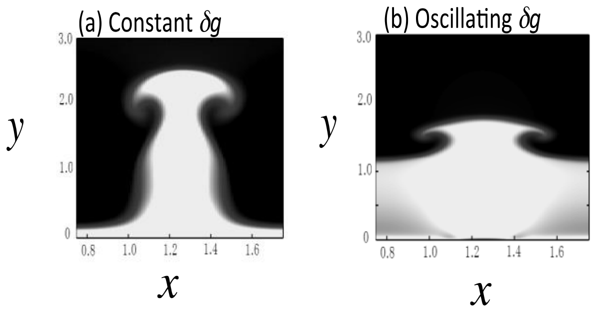

Fig. 1. Example simulation results for the R-T instability mitigation. (a) The 10% acceleration non-uniformity drives the R-T instability as usual, and (b) The 10% acceleration non-uniformity oscillates or wobbles, and reduces the growth significantly.

as usual, and in Fig. 1(b) the phase of δg is shifted or oscillated with the frequency of Ω as stated above for the dynamic mitigation. The example simulation results also supports the effect of the dynamic mitigation mechanism well.

In HIF a fuel target is irradiated by HIBs, when the fuel target is injected and aligned at the center of the fusion reactor. We employ (Pb^+) ion HIBs with the mean energy of 8GeV. The HIB temperature is 100MeV and the HIB transverse distribution is the Gaussian profile. The beam radius at the entrance of a fusion reactor is 35mm and the radius of a fusion reactor is 3m. We employ an Al monolayer pellet target structure with a 4.0mm external radius. The 32-HIBs positions are given as presented in [5]. The HIBs illumination non-uniformity is evaluated by the total relative root-mean-square (RMS) as follows:

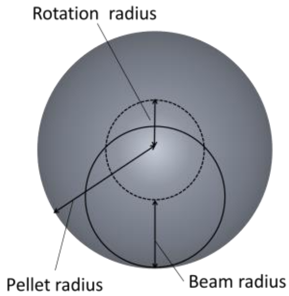

Fig. 2. Schematic diagram for a circularly wobbling beam

$$\sigma_{RMS} = \sum_{i}^{n_r} w_i \sigma_{RMSi}, \sigma_{RMSi} = \frac{1}{\langle E \rangle_i} \sqrt{\frac{\sum_j \sum_k \left(\langle E \rangle_i - E_{ijk} \right)^2}{n_\theta n_\phi}}$$

$$w_i = \frac{E_i}{E}$$

The Bragg peak effect is also included in the energy deposition profile in the target radial direction. In this study, one HIB is divided into many beamlets, and the precise energy deposition is computed.

We have also found that the growth of the R-T instability would be mitigated well by a continuously vibrating non-uniformity acceleration field with a small amplitude compared with that of the averaged acceleration [1, 4]. It is realized by using a wobbling beam. Figure 2 shows a schematic diagram for the wobbling beam. However, in our previous work [6] we found that at the initial stage of the wobbling HIBs illumination the illumination non-uniformity becomes huge and cannot be accepted for a stable fuel target implosion.

The initial imprint of the rotating HIBs illumination is solved by the spiral wobbling HIBs as shown in Fig. 3. When the spirally wobbling beams in Fig. 3 are used, the initial imprint of the non-uniformity at the beginning of the irradiation is greatly reduced about from 14% to 4%. For the spiral wobbling beam the beam radius changes from 3.1mm to 3.0mm at t=1.3τ_{wb}. Here τ_{wb} is the time for one rotation of the wobbling beam axis. The beam rotation radius becomes 2.0mm at t=2.0τ_{wb}. After that, the beam rotation radius is 2.0mm. In this subsection, we employ the spirally wobbling beam for the HIBs illumination non-uniformity study.

3.Conclusions

The imploding fuel mixing is one of the critical issues in HIF. The R-T instabilities take place at the stages of the shock acceleration and the stagnation stage by the non-uniformity of the HIB energy drive and the target fabrication imperfection. The paper shows that the wobbling HIBs would provide a promising method to improve the implosion uniformity in HIF. We are now developing new implosion codes to investigate the implosion dynamics and the implosion non-uniformity effect on the implosion and the ignition in HIF precisely as shown in Fig. 4.

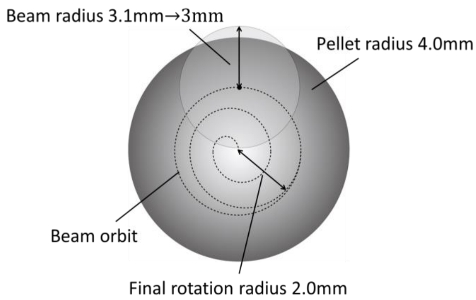

Fig. 3. Schematic diagram for the spiral wobbler.

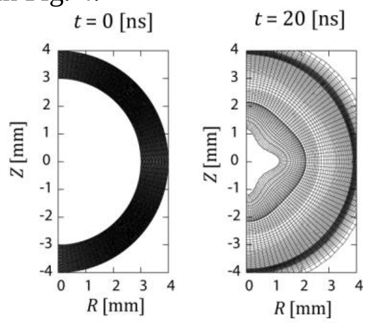

Fig. 4. Example 2D simulation results for a HIF target, which has a deposition energy non-uniformity of 5% with the mode 4. The Lagrange meshes are presented at t= 0 ns and t= 20 ns.

Acknowledgments

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References

[1] S. Kawata, Y. Iizuka, Y. Kodera, A. I. Ogoyski, and T .Kikuchi: Nucl. Instr. Meth. A **606** (2009) 152.
[2] M. H. Emery, J. H. Orens, J. H. Gardner and J. P. Boris:Phys. Rev. Lett. **48** (1982) 253.
[3] S. Kawata: Phys. Plasmas, **19** (2012) 024503.
[4] S. Kawata, T. Sato, T. Teramoto, E. Bandoh, Y. Masubichi, H. Watanabe, and I. Takahashi: Laser Part. Beams **11** (1993) 757.
[5] S. Skupsky and K. Lee: J. Appl. Phys. **54** (1983) 3662.
[6] S. Kawata, T. Sato, T. Teramoto, E. Bandoh, Y. Masubichi, H. Watanabe and I. Takahashi: Laser Part. Beams **11** (1993) 757.