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Spiral wobbling beam illumination uniformity in HIF fuel target implosion

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Abstract. A few % wobbling-beam illumination nonuniformity is realized in heavy ion inertial confinement fusion (HIF) throughout the heavy ion beam (HIB) driver pulse by a newly introduced spiraling beam axis motion in the first two rotations. The wobbling HIB illumination was proposed to realize a uniform implosion in HIF. However, the initial imprint of the wobbling HIBs was a serious problem and introduces a large unacceptable energy deposition nonuniformity. In the wobbling HIBs illumination, the illumination nonuniformity oscillates in time and space. The oscillating-HIB energy deposition may produce a time-dependent implosion acceleration, which reduces the Rayleigh-Taylor (R-T) growth [Laser Part. Beams 11, 757 (1993), Nuclear Inst. Methods in Phys. Res. A 606, 152 (2009), Phys. Plasmas 19, 024503 (2012)] and the implosion nonuniformity. The wobbling HIBs can be generated in HIB accelerators and the oscillating frequency may be several 100 MHz ~ 1 GHz [Phys. Rev. Lett. 104, 254801 (2010)]. Three-dimensional HIBs illumination computations present that the few % wobbling HIBs illumination nonuniformity oscillates with the same wobbling HIBs frequency.

1. INTRODUCTION

Heavy ion beam (HIB) driver has attractive features in inertial confinement fusion (ICF), in high energy density physics and also in ion cancer therapy: a HIB pulse shape is controlled precisely to fit various requirements, a HIB axis is also controllable in precise, a HIB generation energy efficiency is 30 ~ 40%, a HIB particle energy deposition is almost classical and the deposition profile is well known. Especially HIBs deposit their main energy in a deep area of a target material.

The HIB axis controllability provides a unique tool to smooth the HIB energy deposition nonuniformity, and can introduce wobbling or axis-oscillating HIBs [1, 2]. Our recent work presented that the Rayleigh-Taylor (R-T) instability growth can be reduced significantly by the sinusoidally oscillating HIBs in time and space [3, 4].

The 3-D HIBs illumination detail studies show that HIBs illumination uniformity depends strongly on the HIBs illumination scheme [5, 6]. For the wobbling HIBs illumination (see Fig. 1), Ref. [5] shows a sufficiently small nonuniformity for circulaly wobbling HIBs in their steady state, and the nonuniformity is evaluated after the wobbling HIBs energy deposition is steady [6]. However, the wobbling HIBs illumination is time-dependent. We found that the especially initial HIBs illumination nonuniformity becomes large and is not acceptable in ICF. In this paper we present a new HIBs illumination scheme, which always provides a sufficiently low nonuniformity of the HIBs illumination on a direct drive

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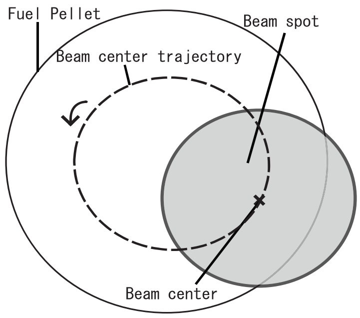

Figure 1. A wobbling beam illumination on a direct-driven spherical target.

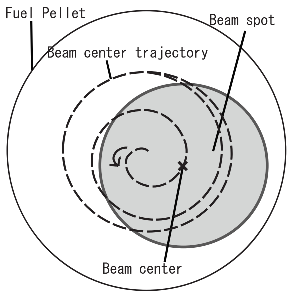

Figure 2. Spiraling HIB. The Spiraling beam axis motion provides a sufficiently low HIBs illumination nonuniformity during the HIBs pulse duration.

spherical target. In the new HIBs illumination scheme, each HIB has a spiraling trajectory (see Fig. 2) so that the time-dependent HIBs illumination realizes a lower nonuniformity ($<3.6\%$) from the initial time to the HIBs pulse termination.

2. SPIRALING HEAVY ION BEAM ILLUMINATION UNIFORMITY

So far the wobbling HIBs illumination has been considered by the time averaged illumination [3–6]. In the time averaged energy deposition onto a spherical direct drive target, the averaged illumination nonuniformity was small, for example, less than a few percent [6]. However, it was found that the initial imprint of the rotating axis HIBs is serious and introduces a large illumination nonuniformity.

In order to reduce the HIBs illumination nonuniformity since the initial time to the beam pulse end, in this paper we propose that each HIB should have a spiral trajectory as shown in Fig. 2 especially in the initial first rotation. After the initial few spiral rotations, the HIB axis trajectories move to circles.

In our study of the HIBs illumination uniformity, we use the OK code [7], in which the detail ion energy stopping power is computed including the beam temperature. The 32-HIBs rotation axes' positions are decided as presented in Ref. [8]. The HIBs illumination nonuniformity is evaluated by the global *rms* [5], including also the Bragg peak effect in the energy deposition profile in the target radial direction. The spatial mode analysis is also performed to find the dominant mode of the illumination nonuniformity.

When we do not employ the spiraling trajectory as shown in Fig. 1, the illumination nonuniformity history shows an unacceptably large nonuniformity during the first several rotations as presented in Fig. 3 (the solid line). The 32-HIBs illumination scheme consists of 6 circles of latitude and the two HIBs illuminating from the top and bottom [8]. Each circle of latitude has 5 HIBs. HIBs located at the

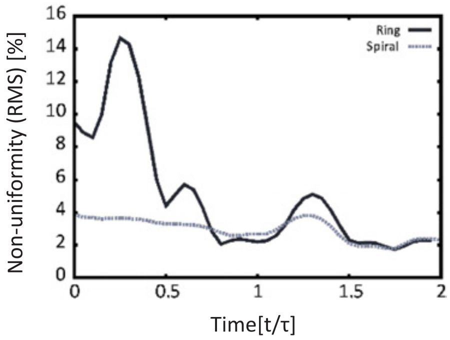

Figure 3. Histories of energy deposition nonuniformities for the circulary moving axies (solid line) and for the spiraling HIBs. The spiraling HIB-axis motion realizes a rather low HIBs illumination nonuniformity.

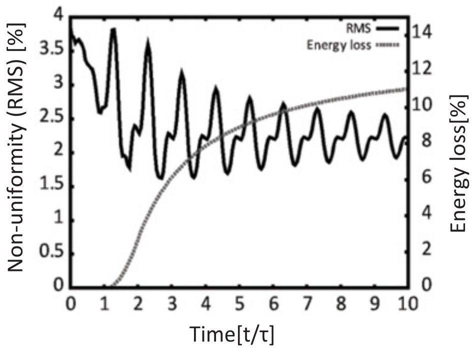

Figure 4. Histories of the spiraling HIBs illumination nonuniformity (the solid line) and the illumination loss (the dotted line). The spiraling HIBs provide a sufficiently uniform deposition uniformity in HIF.

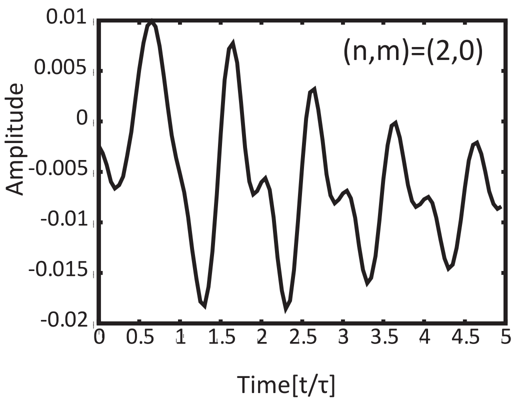

Figure 5. The mode (2, 0) amplitude of HIBs energy deposition nonuniformity versus time.

even number of the circle of latitude start from the top position of the rotation circle and the HIBs in the odd number of the rings start from the bottom of the circle. In this study, the direct drive target radius is 4 mm and the energy deposition layer consists of Al. In this study we employ Pb^{+} ion HIBs with the mean energy 8 GeV. The HIB temperature is 100 MeV and the HIB transverse distribution is the Gaussian profile. The HIB axis rotation radius is 2 mm and the HIB radius is 3 mm [5, 9]. When the

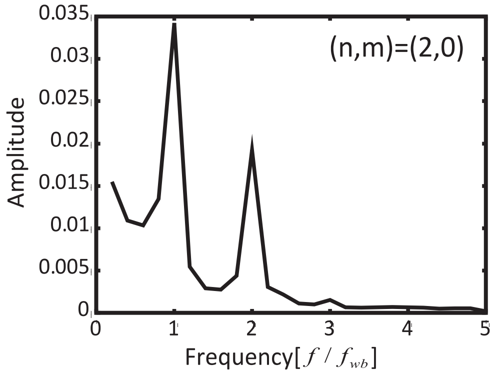

Figure 6. Spectrum of the mode (2, 0) in its frequency space. The frequency f_{wb} is the wobbling HIB frequency. The small nonuniformity of the HIBs energy deposition has the same frequency f_{wb} of the wobblers and also the double frequency $2 f_{wb}$.

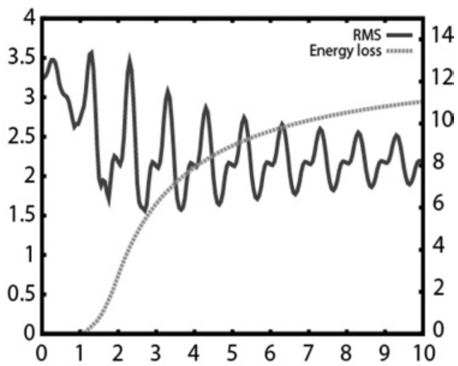

Figure 7. Histories of the spiraling HIBs illumination nonuniformity (the solid line) and the illumination loss (the dotted line). The spiraling HIB radius changes at $t = 1.3\,\tau$ from the initial beam radius of 3.1 mm to 3.0 mm.

spiraling HIBs are employed for the first two rotations, the HIBs illumination uniformity is drastically improved as shown in Fig. 3 (the dotted curve). In Fig. 3 the time is normalized by the wobbling beam axis rotation time τ.

Figure 4 shows the history of the spiraling HIBs illumination nonuniformity as well as the HIB particle illumination loss history. By the spiraling trajectory of the HIB axis, a sufficiently small nonuniformity is successfully realized, and a small part of the HIBs particles do not hit the target in order to obtain the illumination high uniformity. The spectral analyses for the HIBs illumination nonuniformity are also performed based on the spherical harmonic function [5, 6] and show that the mode (n, m) = (2, 0) is dominant throughout the HIBs illumination. Figure 5 shows the amplitude of the mode (2, 0) versus time, and Fig. 6 presents the spectrum of the mode (2, 0) amplitude in its frequency space. In Fig. 6 f_{wb} shows the wobbling HIBs rotation frequency.

The results demonstrate that the small nonuniformity of the HIBs energy deposition has the oscillation with the same frequency and the double frequency with the wobbling HIBs oscillation frequency of f_{wb}. In addition, the total nonuniformity magnitude is suppressed less than 4%. The results in this paper shows a possibility of a rather uniform implosion in HIF based on the wobbling HIBs.

In the analyses presented above, the HIB radius was fixed to be 3 mm. In the wobbling HIBs illumination, the peak of the HIB energy deposition nonuniformity appears in the first few rotations. When the beam radius changes from 3.1 mm to 3 mm at $t = 1.3\,\tau$ during the spiral motion in the first two rotations, we have additional improvement for the HIBs illumination nonuniformity. The peak value of the nonuniformity becomes less than 3.6% (see Fig. 7), although the peak value of the nonuniformity in Fig. 4 was about 4%.

3. CONCLUSIONS

In this paper, we presented the new HIBs illumination scheme of the spiraling HIBs, so that the HIBs illumination uniformity is drastically improved. Throughout the HIB input pulse, the beam illumination nonuniformity is kept low, that is less than about 4%. The fuel target implosion nonuniformity must be reduced less than a few percent [10]. The wobbling HIBs illumination provides a sufficiently small acceleration nonuniformity, which may help to reduce the Rayleigh-Taylor instability growth [3, 4]. The small-amplitude nonuniformity oscillation frequency is the wobbling oscillation frequency and the double of the wobbling frequency. The wobbling HIBs may supply a new stable and uniform implosion mode in HIF [3, 4].

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References

[1] H. Qin, R. Davidson, B. G. Logan, Phys. Rev. Lett. **104**, 254801 (2010)
[2] N. A. Tahir, A. Shutov, A. R. Piriz, I. V. Lomonosov, C. Deutsch, P. Spiller, T. Stöhlker, Plasma Phys. Control. Fusion **53**, 124004 (2011)
[3] S. Kawata, T. Sato, T. Teramoto, E. Bandoh, Y. Masubuchi, H. Watanabe, I. Takahashi, Laser Part. Beams **11**, 757 (1993)
[4] S. Kawata, Y. Iizuka, Y. Kodera, A.I. Ogoyski, T. Kikuchi, Nucl. Instr. Meth. Phys. Res. **A606**, 152 (2009)
[5] S. Miyazawa, A.I. Ogoyski, S. Kawata, T. Someya, T. Kikuchi, Phys. Plasmas **12**, 122702 (2005)
[6] J. Runge, B. G. Logan, Phys. Plasmas **16**, 033109 (2009)
[7] A. I. Ogoyski, S. Kawata, P. H. Popov, Comput. Phys. Comm. **181**, 1332 (2010) and references therein
[8] S. Skupsky, K. Lee, J. Appl. Phys. **54**, 3662 (1983)
[9] T. Someya, A. I. Ogoyski, S. Kawata, T. Sasaki, Phys. Rev. ST-AB **7**, 044801 (2004)
[10] S. Kawata, K. Niu, J. Phys. Soc. Jpn. **53**, 3416 (1984)