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Optimization of illumination configuration for polar direct drive
レーザー核融合における円筒対称直接照射配位の最適化

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We address laser illumination configuration for polar direct drive. The polar angles and deviations of the beam axes from the target center are optimized such that the root-mean-square non-uniformity of laser absorption is to be minimized. The present scheme provides practical and realistic illumination system for future laser fusion reactor.

1. Introduction

Beam configuration of such laser fusion facilities as NIF in U.S. and LMJ in France are originally designed for the irradiation system by indirect drive, where a number of laser beams (N_B ~ 200) are allocated on the chamber surface in a cylindrically symmetric manner. Therefore, the beam configuration is tuned such that a highest illumination by the secondary x-ray radiation hits the spherical pellet embedded in the cylindrical high-Z casing [1].

However, if these beams are directly irradiated on a spherical pellet with the beam axes being through the target center as is the case for orthodox direct drive illumination schemes, the laser absorption uniformity is expected to be fatally degraded compared with its best performance for indirect drive.

In the present work, we provide optimized direct-drive illumination configuration in use of such polar-arrayed beams for indirect drive as NIF or LMJ that achieves high illumination uniformity at a practically acceptable level. The optimization is numerically done to minimize the root-mean-square (rms) deviation of absorption efficiency distribution on the spherical pellet surface,σ_{rms}[2,3], based on the idea of potential-gradient method, where focal points and gaps of the beam axes from the target center of all the individual beams are taken into account as free parameters. The illumination configurations given by the present method are expected to apply to such direct drive schemes as shock ignition as well as the orthodox central spark ignition, in use of NIF and LMJ.

2. Geometrical factor

The fundamental assumption employed here is that the energy influx onto the ablation surface brought by the kth beam is also axially symmetric around its beam axis $\widehat{\Omega_k}$, where the hat denotes a unit vector, and is expanded in Legendre polynomials:

$$I_k(\hat{\boldsymbol{r}}) = \overline{I_k}\left[1 + \sum_{n=1}^{\infty} a_n P_n\left(\hat{r}\cdot\widehat{\Omega_k}\right)\right] \qquad (1)$$

Where $\hat{\boldsymbol{r}}$ is the unit vector for an arbitrary observing point, and $\overline{I_k}$ is the average intensity over the sphere. The coefficients $\{a_n\}$ are uniquely determined by the profile, and are common for each beam. Such processes as energy deposition and transport of absorbed beam energy, after all, are attributed to the coefficients $\{a_n\}$. The total rms deviation, $\sigma_{rms} = (\sum_n \sigma_n^2)^{1/2}$, is composed of factors of each mode[4]:

$$\sigma_n = \frac{a_n}{\sqrt{2n+1}} G_n \qquad (2)$$

Where the first time accounts for the single beam pattern, while the second term defined by [4, 5]

$$G_n = \left[\sum_{j=1}^{N_B}\sum_{k=1}^{N_B} P_n\left(\widehat{\Omega_j}\cdot\widehat{\Omega_k}\right)\overline{I_j}\,\overline{I_k}/I_T^2\right]^{1/2} \qquad (3)$$

Accounts for the irradiation configuration, and is termed the geometrical factor, where $I_T = \sum_k \overline{I_k}$. The separability (Eq. 3), has been first shown by [4], and owing to this significant feature the irradiation system can be optimized in terms of only the pointing $\widehat{\Omega_k}$ and the energies$\{\overline{I_k}\}$ of the beams.

3. Cylinder Symmetrical System

Fig.1. shows the schematic picture of the cylindrically symmetric irradiation system with two rings per hemisphere. The beam axes do not point to the target center, and arranged on N_C cone surfaces ($N_C = 2$ in Fig. 1.); the *i*th cone is characterized by the polar angle θ_i, the gap of beam axes from a target centerb_i, and the total energy ε_i. For simplify, we start with the limiting case where the number of beams is infinity large ($N_B = \infty$) and are divided into N_{max} groups characterized by cone angles $\{\theta_1, \ldots, \theta_{N_{max}}\}$, gaps of the beam axes from the target center $\{b_1, \ldots, b_{N_{max}}\}$, and energies $\{\epsilon_1, \ldots, \epsilon_{N_{max}}\}$ [1]. Moreover, energies were normalized, and ϵ_2, and $\epsilon_{N_{max}}$ were made into ratio to ϵ_1 as $\epsilon_1 = 1$ (Fig. 2.).

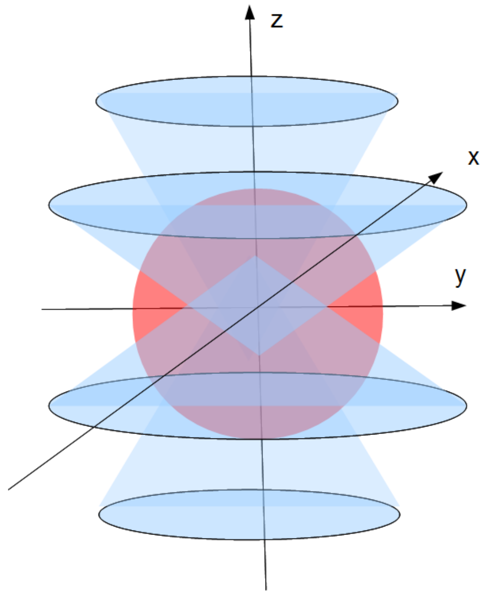

Fig. 1. Schematic view of the cylindrical irradiation system for $N_C = 4$ case. The beam axes do not point to the target center

4. Result and Conclusion

Fig. 2 shows the calculation result of the cylindrically symmetric irradiation system with three rings per hemisphere.

By the cylindrical symmetrical irradiation system, it turned out that more uniform irradiation can be enabled by making a target irradiate with laser centering on a target in the shape of a ring. It is expected that this calculation result will be adapted also to laser irradiation systems, such as the National Ignition Facility (NIF) in U.S. and Laser Mega Joule (LMJ) in France, by the indirect drive.

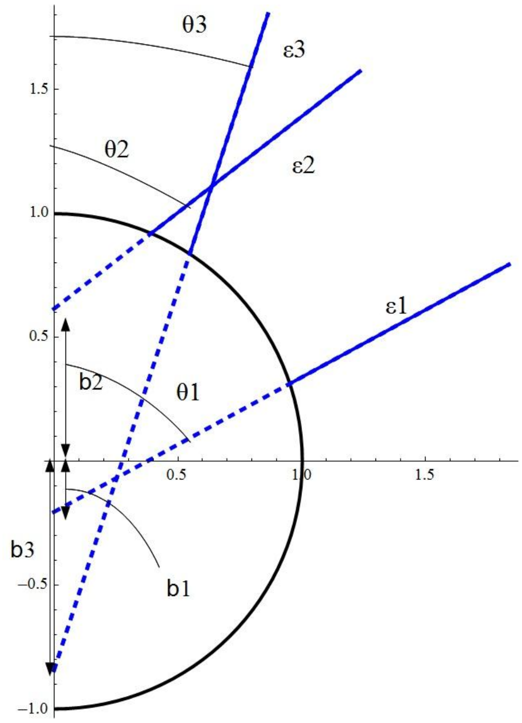

Fig. 2. The calculation result of the cylindrically symmetric irradiation system with three rings per hemisphere

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