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Study of Irradiation Uniformity Using a Lens Array and Non-Spherical Principal Focusing Lens

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Abstract

A transmission function of a lens array and computed model for intensity distribution of laser on target are given. The code for irradiation intensity on target is developed, while laser beam is incident on target by using a lens array and the non-spherical principal focusing lens. Laser irradiation uniformity of one beam and many beams for Shenguang with many small lenses is studied using this code, as well as that of one beam and many beams for Shenguan with one small lens. The results are obtained including the intensity distribution of laser beams on targets and root-mean-squared intensity fluctuation. The numerical computation indicated that uniformity with many small lenses is better than that with one small lens,uniformity of four beams is better than that of one beam.

Keywords:
irradiation uniformity, lens array, transmission function

1. Introduction

According to the present status for study of laser irradiation uniformity, it is impossible that the smoothing technology for time-space incoherence on Shenguang laser system is developed recently, such as random phase plate (RPP) [1,2] smoothing by spectral dispersion (SSD) [3] and kinoform phase plate (KPP) [4,5] etc. Academician Ximing Deng *et al.* presented a new method of focusing by using a lens array (LA). Wide range uniform illumination could be obtained on the target surface. The better results were obtained in researching equation of state. The near-field irradiation is used in this method. The purpose in this paper is that whether Rayleigh-Taylor (RT) instability research is possible using a lens array and the non-spherical principal focusing lens?

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2. Laser Intensity at Target Surface by Using a LA and the Non-Spherical Principal Focusing Lens

Irradiation system by using a LA and the non-spherical principal focusing lens is plotted in Fig.1. It is composed of an array of many similar smaller lenses and a non-spherical principal focusing lens placed behind the lens array. The lens array splits the incident laser beam into many partial beams. Each of these beamlets is focused on the compound focal surface, then diverge through a non-spherical principal focusing lens, and illuminates the target. In order to study laser irradiation uniformity on the target, firstly a transmission rate function of a lens array is given by

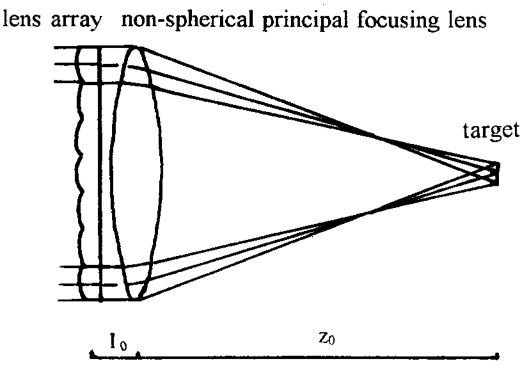

Fig. 1 Configuration of the lens array illumination system.

$$t_{\mathrm{LA}}(x,y)=\sum_m\sum_n p(x-x_{mn},y-y_{mn})\cdot\exp\left\{-\mathrm{i}\frac{k_0}{2f_e}\left[(x-x_{mn})^2+(y-y_{mn})^2\right]\right\}\exp\left\{\mathrm{i}\left[k_0\delta s(N-1)+\psi_{mn}\right]\right\},\quad(1)$$

where f_e is the focal length of the small lens and $k_0=\frac{2\pi}{\lambda_0}$, λ_0 are the wave number and the wavelength of the incident light respectively, $\mathrm{i}=\sqrt{-1}$, (x_{mn}, y_{mn}) are the central coordinate of the lens element for row m and column see Fig.2 $p(x-x_{mn}, y-y_{mn})$ is the aperture function, i.e. $P=1$, if $(x-x_{mn}, y-y_{mn})$ locate within the aperture for the lens element mn, otherwise $P=0$, N is reflectance, ψ_{mn} is a random number from 02, δ is a parameter S takes value, it is shown as

$$S=\sqrt{(x-x_{mn})^2+(y-y_{mn})^2}\cos\left(\mathrm{arctg}\frac{y-y_{mn}}{x-x_{mn}}-\alpha_{mn}\right),\quad(2)$$

where arctg $\frac{y-y_{mn}}{x-x_{mn}}$ takes a value from 02, α_{mn} is a random number from 02.

The laser electric field E_t of a point (x_t, y_t) on the target surface is shown as

$$E_t(x_t,y_t,z)=\iint_{\Sigma} t_{\mathrm{LA}}(x,y)\exp\left[\mathrm{i}k_0L(x,y,x_t,y_t)\right]\cos\varphi\,\mathrm{d}x\mathrm{d}y,\quad(3)$$

where Σ denotes integral of all the incident laser beams. for each lans array, we have

$$E_t^{mn}(x_t,y_t,z)=\iint_{S_{mn}} f(x,y)\mathrm{d}x\mathrm{d}y=\iint_{S_{mn}}\exp\left\{-\mathrm{i}\frac{k_0}{2f_e}\left[(x-x_{mn})^2+(y-y_{mn})^2\right]\right\}\exp\left\{\mathrm{i}\left[k_0\delta s(N-1)+\psi_{mn}\right]\right\}\exp\left[\mathrm{i}k_0L(x,y,x_t,y_t)\right]\cos\varphi\,\mathrm{d}x\mathrm{d}y,\quad(4)$$

$$L(x,y,x_t,y_t)=L+z+\frac{1}{2B}\left[A(x^2+y^2)-2(xx_t+yy_t)+D(x_t^2+y_t^2)\right],\quad(5)$$

$$\begin{pmatrix}A & B\\ C & D\end{pmatrix}=\begin{pmatrix}1-z/f_a & l_0+z+l_0z/f_a\\ -1/f_a & 1-l_0/f_a\end{pmatrix},\quad z=z_0+y_t\mathrm{tg}\theta,\quad(6)$$

$$\cos\varphi=\frac{z\cos\theta+y\sin\theta}{\sqrt{x^2+y^2+z^2}}\approx\frac{z_0\cos\theta+y\sin\theta}{z_0}\left(1-\frac{1}{2}\frac{x^2+y^2}{z_0^2}\right),\quad(7)$$

Where f_a is the focal length of the principal lens. Substituting Eqs.(1)(2), (5)-(7) into (3) or (4) it is obtained the field intensity distribution on the target at incident angle θ. When four beams are incident simultaneously, laser intensity distribution on the target is

$$I(E_{t1}+E_{t2}+E_{t3}+E_{t4})\bullet(E_{t1}^*+E_{t2}^*+E_{t3}^*+E_{t4}^*).\quad(8)$$

3. Numerical Computation and Result Analysis

Firstly we discuss integral limit in computational lens array see Fig.2. This lens array system, shown in Fig.2, is composed of 19 whole hexagon smaller lenses and 12 part hexagon smaller lenses. For whole hexagon smaller lens, the field intensity on the target is

$$E_t^{mn}(x_t,y_t,z)=\int_{y_{mn}-25}^{y_{mn}}\int_{x_1}^{x_2}f(x,y)\mathrm{d}x\mathrm{d}y+\int_{y_{mn}}^{y_{mn}+25}\int_{x_3}^{x_4}f(x,y)\mathrm{d}xy\quad(9)$$

For part hexagon smaller lenses, the field intensity on the target is

1.5: $$E_t^{mn}(x_t, y_t, z) = \int_{y_{mn}-25}^{y'_R}\int_{x_1}^{x_2} f(x, y)\mathrm{d}x\mathrm{d}y + \int_{y'_R}^{y_{mn}}\int_{x_1}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y + \int_{y_{mn}}^{y_R}\int_{x_3}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y \quad (10)$$

2.4: $$E_t^{mn}(x_t, y_t, z) = \int_{y_{mn}-25}^{y'_{mn}}\int_{x_1}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y + \int_{y'_{mn}}^{y_n}\int_{x_3}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y \quad (11)$$

3.1: $$E_t^{mn}(x_t, y_t, z) = \int_{y_{mn}-25}^{y_{mn}}\int_{x_1}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y + \int_{y'_{mn}}^{y_n}\int_{x_3}^{\sqrt{R^2-y^2}} f(x, y)\mathrm{d}x\mathrm{d}y \quad (12)$$

where

$$x_1 = (x_{mn} - 31.6) - 0.632(y - y_{mn}) \quad (13)$$

$$x_2 = (x_{mn} - 31.6) - 1.896(y - y_{mn}) \quad (14)$$

$$x_3 = (x_{mn} - 31.6) + 0.632(y - y_{mn}) \quad (15)$$

$$x_4 = (x_{mn} + 31.6) - 1.896(y - y_{mn}) \quad (16)$$

$$y_R = y_{mn} - \frac{\left[0.632(x_{mn} - 31.6) + y_{mn}\right]}{(1 + 0.632^2)} + \frac{\sqrt{\left[0.632(x_{mn} - 31.6) + y_{mn}\right]^2 - (1 + 0.632^2)\left[(x_{mn} - 31.6)^2 + y_{mn}^2 - R^2\right]}}{(1 + 0.632^2)} \quad (17)$$

$$y'_R = y_{mn} - \frac{\left[1.896(x_{mn} - 31.6) + y_{mn}\right]}{(1 + 1.896^2)} + \frac{\sqrt{\left[1.896(x_{mn} + 31.6) + y_{mn}\right]^2 - (1 + 1.896^2)\left[(x_{mn} + 31.6)^2 + y_{mn}^2 - R^2\right]}}{(1 + 1.896^2)} \quad (18)$$

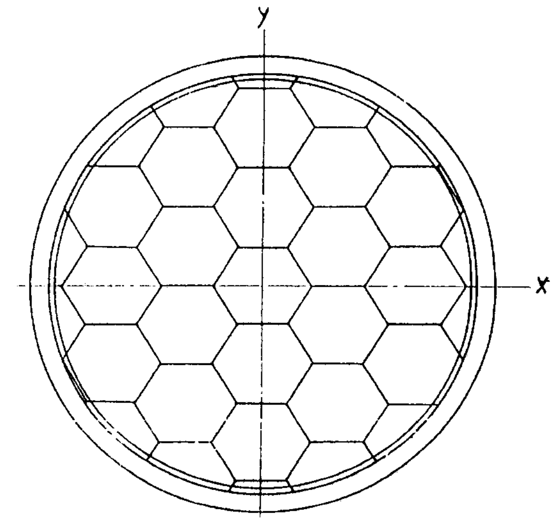

Fig. 2 Schematic illustration of lens array composition.

where $f(x, y)$ is shown in Eq.(4) x_{mn} and y_{mn} is given in Table 1. The value of x_t and y_t is from 0.8mm. Some parameters $l_0, f_e, f_a, \theta, \delta, z_0$ are given in Table 2. If the result for one beam is obtained,the results for other three beams can be obtained y to rotating turn on 900°, 1800° 2700°, respectively. Then the field intensity on the target for four beams can be obtained using the superposition method. Thus the laser intensity distribution on the target surface can be determined.

We developed a computer code "Parea". The total integral is composed of all the smaller lenses integral. In the region of the smaller lens, the several integral small region is divided. The mesh number in x-direction and y-direction is 128128 (or 6464). Laser irradiation uniformity of one beam and four beams for Shenguang-with many small lenses is studied using this code, as well as that of one beam and four beams for Shenguang with one small lens. The irradiation intensity distribution of four beams for Shenguang with many small lenses is shown in Fig.3. Figures 3(a), (b), (c) and (d) denote (i, 1), (i, 20), (i, 100) and (i, 128) respectively. Figures

Table 1 Data of x_{mn} and y_{mn}

	-3	-2	-1	0	1	2	3
-5			-47.4,-125		47.4,-125		
-4		-94.8,-100		0,-100		94.8,-100	
-3			-47.4,-75		47.4,-75		
-2		-94.8,-50		0,-50		94.8,-50	
-1	-142.2,-25		-47.4,-25		47.4,-25		142.2,-25
0		-94.8,0		0,0		94.8,0	
1	-142.2,25		-47.4,25		47.4,25		142.2,25
2		-94.8,50		0,50		94.8,50	
3			-47.4,75		47.4,75		
4		-94.8,100		0,100		94.8,100	
			-47.4,125		47.4,125		

Table 2 Data-in for computer model

physical quantity symbol and meaning	f_e focal length of the small lens	f_a focal length of the principal lens	l_0 distance between the LA and the principal lens	z_0 distance between the principal lens and the target	λ_0 laser wavelength
value	77m	750mm	0.6m	750mm250m	1.06m
physical quantity symbol and meaning	N reflectance of the small lens	mn random number	mn random phase	direction parameter	angle between the principal lens and the target surface
value	1.5063	radian	radian	05	24^0

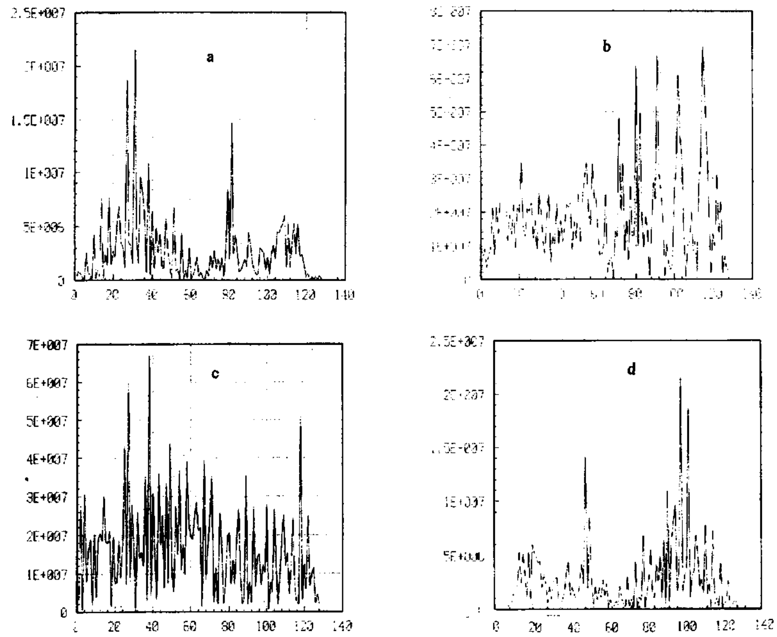

Fig. 3 Laser intensity distribution in x-direction a (i, 1) b (i, 20) c (i, 100) d (i, 128).

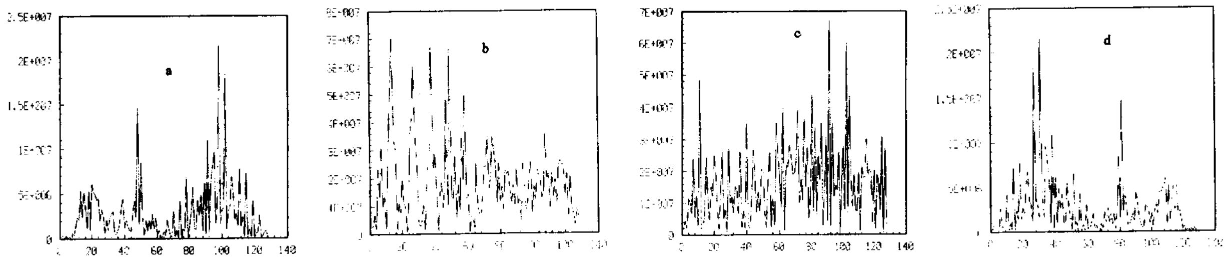

Fig. 4 Laser intensity distribution in y-direction a (1, j) b (20, j) c (100, j) d (128, j).

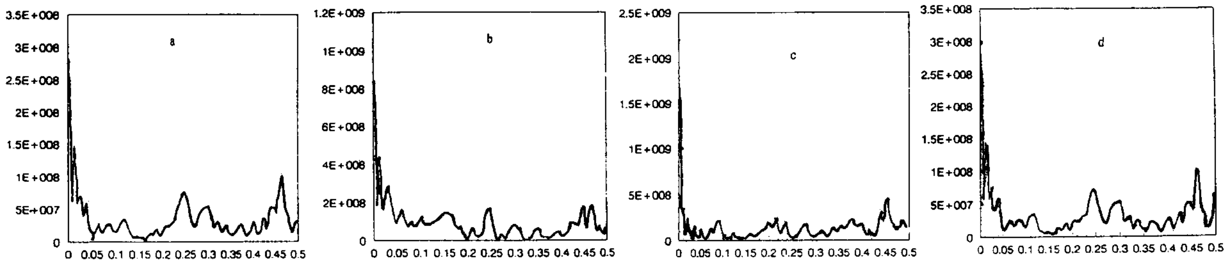

Fig. 5 Laser intensity spectrum distribution in kx direction (correspond to Fig.3).

4(a), (b), (c) and (d) denote (1, j), (20, j), (100, j) and (128, j) respectively. The root mean-squared intensity fluctuation $\eta = \frac{1}{i \cdot j} \sum_{ij} \sqrt{(I - \bar{I})^2}/\bar{I} \approx 0.8$. Figures 5(a), (b), (c) and (d) denote the spectrum distribution correspond to Fig.3, respectively. The computed results indicated that uniformity with many small lenses is better than with one small lens,uniformity of four beams is better than of one beam. The spectrum distribution indicated that the intensity of long wavelength and short wavelength is higher. It may be the effect of boundary. In addition,if the distance between the target and the principal focusing lens is greater than the focal length,i.e 750mm + 250mm the irradiation uniformity can be improved. Nevertheless,in general this method is not better than other smoothing technology of time-space incoherence [1-7].

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