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Study on the superposition characteristics of distorted beam in far field

Chao Wu, Rongzhu Zhang*

College of Electronics and Information Engineering, Sichuan University, Chengdu 610065, China

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Based on extended Huygens–Fresnel principle, an incoherent combination model of laser beams with random phase distorted is established. The characteristics of the combined focal spots are studied in detail. Using the numerical method, the far-field distribution of Flattened Gaussian beams and Gaussian beams with random phase distortion is simulated. Specially, the relation between the RMS, PSD of focal spot and different number of combination beams in the far-field is discussed. The results show that incoherent beam combination has a conspicuous smoothing effect on their focal spot, and Gaussian beams has the better ability to improve the far-filed smoothing than Flattened Gaussian beams.

1. Introduction

High power laser with good beam quality is widely applied in many fields, such as energy, scientific research and industry. The traditional large-aperture laser can increase output power, however, some shortcomings are unavoidable, for instance, bulky volume, high cost, and high thermal management cost [1]. Those deficiencies limit the further enhancements of output power. Multi-beam laser combination is an effective approach to obtain high-power laser output while maintaining good beam quality [2]. Techniques developed for beam combination can be divided into two categories: (1) coherent beam combination, and (2) incoherent beam combination. Comparatively speaking, the system of incoherent beam combination is relatively simple because it is not necessary to guarantee the uniformity of beamlets parameters, and the quality of the output light finally depends on the combination apparatus. Incoherent beam combination is that all the beamlets converge in the near or far field by using some optical elements. And then all the output energy of the beamlets can be superimposed on the target. However, some unavoidable objective factors, such as fabrication errors of the elements, external ambient vibrations, air turbulence, will cause the random phase modulation on the laser wavefront. It reduces the beam quality and causes the non-uniform intensity distribution in the focal plane. What we mainly discuss in this paper is that the smoothing characteristics comparison of far-field beam combination between distorted FGB and GB.

Using the random theory, based on generalized Huygens–Fresnel principle, and taking the incoherent beam combination method, we study the energy superposition characteristic of FGB and GB with random phase distortion and compare their smoothing properties in far field.

2. Basic model

As shown in Fig. 1, assume that $M \times N$ individual FGB or GB is positioned on spherical surface. The distance from all beams to point P is f. Ideally, there will be a high energy spot in the focal plane (P) after multi-beam incoherent combination.

For one beamlets, its far-field complex amplitude can be given by Fresnel diffraction integral formula [3] after propagating through a lens.

$$U(x,y) = \frac{\exp(ikf)}{i\lambda f} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} U_0(x_0,y_0) \times \exp\left\{\frac{ik}{2f}[(x-x_0)^2+(y-y_0)^2]\right\} dx_0 dy_0 \quad (1)$$

where $U_0(x_0, y_0)$ is the near-field complex amplitude of beamlets, $k = 2\pi/\lambda$ is wave number, $i = \sqrt{-1}$, λ is laser wavelength, f is the focal length of lens.

Thus, the corresponding irradiance in the far field is

$$I(x,y) = \left|U(x,y)\right|^2 \quad (2)$$

Lasers ranging on spherical surface can form a 2D rectangular symmetry plane laser array though projecting. The irradiance of

* Corresponding author.
E-mail address: zhang_rz@scu.edu.cn (R. Zhang).

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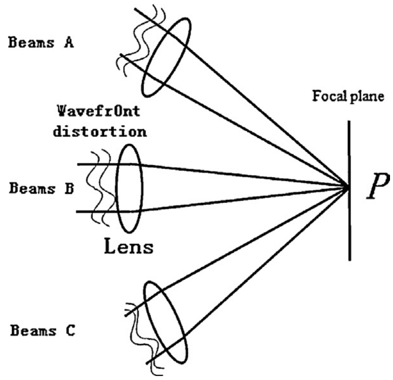

Fig. 1. Schematic of incoherent beam combination model for distorted beam.

$M \times N$ array beams composed of $U_{11}, U_{12}, U_{13}\ldots$ for the incoherent combination is

$$I_{\text{incoh}}(x,y)=\sum_{m=1}^{M}\sum_{n=1}^{N}\left|U_{mn}(x,y)\right|^2 \quad (3)$$

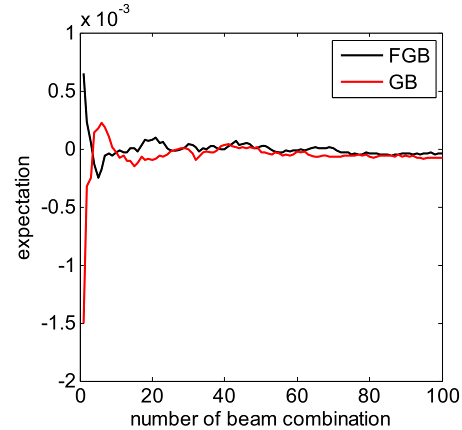

Fig. 5. Variation curves of expectation with different number of beam combination.

where U_{mn} is the complex amplitude of mth line, nth row beamlets.

In the real propagation process, the random phase distortion produced under external influence cannot be ignored. The random phase distortion will result in the fact that neither the focus

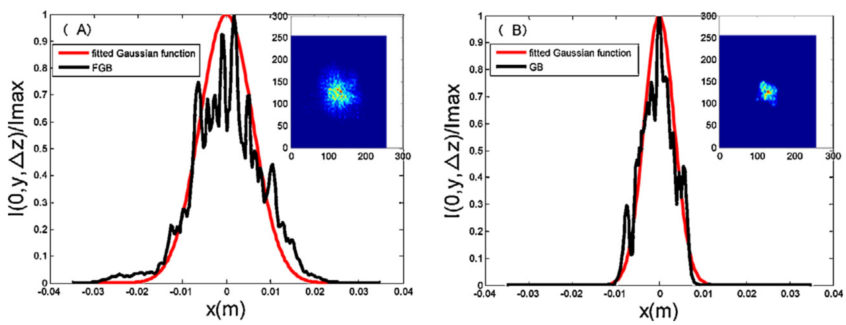

Fig. 2. Focus and 1D normalized irradiance distribution of different beamlets: (A) FGB; (B) GB.

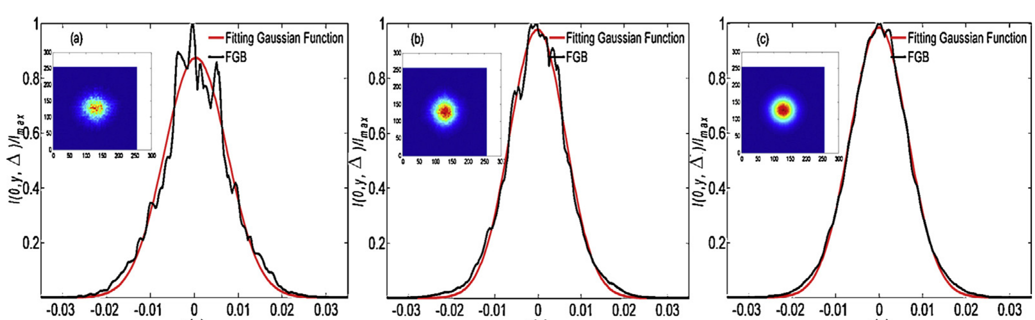

Fig. 3. 1D normalized irradiance distribution and focus of FGB with different number of beam in the far field: (a) 4; (b) 16; (c) 100.

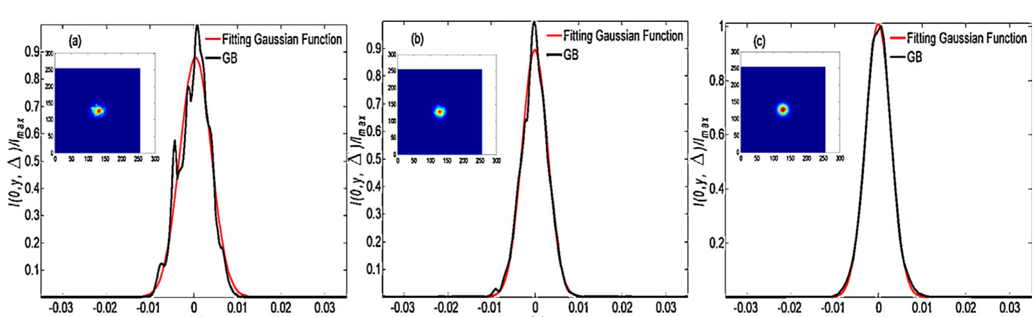

Fig. 4. 1D normalizedirradiance distribution and focus of GB with different number of beam combination in the far field: (a) 4; (b) 16; (c) 100.