Optik 143 (2017) 59–65

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Compensation for the spatial periodic modulation of the near-field beam with an improved iterative weight-based method

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ARTICLE INFO

Article history:
Received 21 March 2017
Accepted 15 June 2017

Keywords:
Improved weight-based method
Spatial periodic modulation
Near-field beam quality

ABSTRACT

An improved iterative weight-based method is studied to compensate for the spatial periodic modulation (SPM) of the near-field beam. Based on the beam angular spectrum transmit formula (ASTF), the required phase that compensates for the intensity distribution of the incident SPM beam is iterated by this algorithm, which can contribute to improve the uniformity and quality of the output near-field beam. The experimental results show that the similarity value ε is improved from 0.9878 to 0.9947 and is getting closer to 1. The modulation degree M of the output near-field beam is decreased from 1.3631 to 1.3401 and the contrast degree C is decreased from 0.3018 to 0.2635 by using the liquid-crystal spatial light modulator (SLM). This indicates that the experiment verifies the feasibility of this iterative method to compensate for the SPM of the near-field beam.

1. Introduction

In the process of transmission and amplification of high-power laser beam, the non-uniformity of optical element materials, defects created by the processing of the component surface and the gain inhomogeneity in slab amplifiers result in the spatial periodic modulation (SPM) [1,2] in the near-field beam. The nonlinear gain of special frequency of the SPM under high throughput operation is very fast and the subsequent optical elements may be destroyed by the effect of small-scale self-focusing [3,4]. Therefore, it is crucial to minimize or remove the SPM of the near-field beam in the high power laser system. In addition, controlling the near-field beam uniformity and optimizing the near-field beam quality are able to enhance the load capacity and the output energy of the high power laser system as well as reduce the cost of the laser system.

Spatial filter is the most common method used in high power laser system to filter out the SPM of the near-field beam [5,6]. But with the use of spatial filter in high power laser beams, there are pinhole closure and back-reflections problems [7,8]. In order to solve these problems, just as reported in the previous literature that different types of pinhole [9] and slit spatial filter [10] for large laser systems were proposed. An improved spatial filter and even new technique without processing in the frequency domain in the spatial filter for controlling the SPM are worthy of study. Furthermore, in recent years, as with adaptive optics, a practical control system is driven by closed-loop feedback. Adaptive spatial beam shaping is an effective method to control the near-field beam intensity and improve the near-field beam quality by using a programmable liquid-crystal spatial light modulator (SLM) [11,12]. SLM is a versatile device that has an important application prospect in the field

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http://dx.doi.org/10.1016/j.ijleo.2017.06.057
0030-4026/

of laser beam shaping [13,14], adaptive optics [15] and holographic measurement [16]. The beam shaping system using a SLM has undergone a successful transition from initial proof-of-principle demonstrations to an implementation in several high-power laser beams such as National Ignition Facility (NIF) in the USA [17], OMEGA EP at the University of Rochester [18]. It is expected to provide an effective and rapid technical method of improving the near-field beam quality, if laser beam shaping is performed with SLM while the compensation and control of the SPM of the near-field beam are considered.

In this paper, we discuss a spatial beam shaping algorithm based on SLM to compensate for the SPM of the near-field beam. This spatial beam shaping algorithm is called iterative weight-based method [19], which has been taken into account a parametric extension of the G-S algorithm. Based on this algorithm, we present a method of auto-select parameter for compensating for the SPM, which can get more appropriate parameter quickly instead of the attempt method to determine the parameter. In addition, we put forward some methods to avoid that the denominator is zero in the iterative process. The beam angular spectrum transmit formula (ASTF) used in the iterative process and the principle of this simple iterative algorithm will be presented in Sec. 2. The feasibility of this method is verified experimentally by the He-Ne laser beam. The experimental results are shown in Sec. 3. The reduction for the modulation degree M and the contrast degree C with describing the effect of SPM in the near-field beam are also presented. Finally, Sec. 4 concludes with a brief summary of the improved iterative weight-based method to compensate for the SPM of the near-field beam and points to the future study direction of this work.

2. Principle of the iterative weight-based method for controlling SPM

It is necessary to perform the light diffraction operation and its inverse in the phase retrieval iterative process. Due to the fact that the angular spectrum theory strictly satisfies the Helmholtz equation, it can obtain more accurate and reliable results when we use the theory to deal with the light diffraction calculation during the iterative process [20]. The angular spectrum theory provides theoretical support for the design of the improved iterative weight-based algorithm. Therefore, we will first briefly introduce the angular spectrum theory used in this paper, and then focus on the description and analysis of the improved iterative weight-based method.

2.1. The angular spectrum propagation theory

The angular spectrum propagation theory is one of the cornerstones for numerical simulation of the light free-space diffraction. In Cartesian coordinates, assuming that $E_i(x_i, y_i)$ and $E_o(x_o, y_o)$ are light wave complex amplitude of the input plane and the observation plane, respectively. After a certain spatial distance d diffraction, according to Fresnel diffraction integral, $E_o(x_o, y_o)$ can be written as [20,21]

$$E_o(x_o, y_o) = \frac{\exp(ikd)}{i\lambda d} \int\int_{-\infty}^{\infty} E_i(x_i, y_i) \exp\{\frac{ik}{2d}[(x_o - x_i)^2 + (y_o - y_i)^2]\} dx_i dy_i \tag{1}$$

Then with the help of Fourier transform, the precise solution of diffraction field $E_o(x_o, y_o)$ without the near-axis approximation can be represented as

$$E_o(x_o, y_o) = F^{-1}\{F\{E_i(x_i, y_i)\}H(f_x, f_y)\} \tag{2}$$

where

$$H(f_x, f_y) = \exp[ikd\sqrt{1 - (\lambda f_x)^2 - (\lambda f_y)^2}] \tag{3}$$

Eq. (2) is the angular spectrum transfer function (ASTF). f_x, f_y are coordinates in the frequency domain and λ is the wavelength with $k = 2\pi/\lambda$. According to Eq. (2), we can obtain the expression of $E_i(x_i, y_i)$ by the inverse operation of angular spectrum propagation

$$E_i(x_i, y_i) = F^{-1}\{F\{E_o(x_o, y_o)\}H^*(f_x, f_y)\} \tag{4}$$

where

$$H^*(f_x, f_y) = \exp[-ikd\sqrt{1 - (\lambda f_x)^2 - (\lambda f_y)^2}] \tag{5}$$

$H^*(f_x, f_y)$ and $H(f_x, f_y)$ are conjugate. They can be considered as transfer function. Actually, the free-space diffraction of the light wave and its inverse are equal to the transformation of the light wave through a linear space invariant system. We can use the fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT) to carry out the discrete numerical calculation of Eqs. (2) and (4).