



Laser Far-Field Focal Spot Measurement Method Based on Multi-step Phase Recovery

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Abstract. Laser far-field focus measurement is an important method for measuring laser beam power. The measurement of optical power is a key problem in many fields, such as laser technology, metrology, etc. In multi-step phase recovery on for high-precision measurement of the position and size of the far-field focus. The method can be divided into two steps: firstly, the spatial intensity distribution of laser beam is calculated by using the fast Fourier transform (FFT) algorithm; Secondly, it uses laser far-field focus measurement to measure the size of laser beam spot on an object. This method is based on phase recovery technology, which uses two or more measurements to determine the size of the object. The first measurement is carried out at a certain distance from the object, and then another measurement is carried out at a relatively close distance from the same object. If the size between these two measurements does not change, it can be assumed that the size of the focus itself does not change.

Keywords: Phase recovery · Laser · High-precision measurement

1 Introduction

Laser far field focal spot diagnosis has gone through the research process from direct measurement to indirect reconstruction. Direct measurement methods mainly include scanning method, photosensitivity method, ablation method, long focal lens imaging method, wedge beam splitting method, array camera method and schlieren method. The scanning method has poor real-time performance and requires high stability of the light source. Photosensitivity method and ablation method cannot be measured quantitatively [1]. The limited by the linear response of CCD, and cannot obtain complete focal spot distribution. In the wedge beam splitting method, the surface error of the wedge leads to additional wave aberrations and the two reflections of the beam on the wedge lead to additional optical path differences. The light spot obtained by CCD detection is not the real far-field focal spot. The array camera the dynamic range measurement and the size of the target plane, and still cannot measure information the focal spot completely. Schlieren method requires high stability of optical path and high performance of occluder.

In order to avoid the disadvantages of the direct measurement method, the indirect measurement method realizes the high-precision diagnosis the -energy by measuring the complex amplitude of the laser near field [2]. According to Kirchhoff diffraction theory,

the process of laser near-field transmission to far-field transmission is Fraunhofer diffraction process, that is, the intensity laser is related to the power spectrum of laser near-field complex amplitude distribution, so the accuracy of high-energy laser near-field complex amplitude measurement affects the measurement accuracy. The intensity distribution of laser spot laser beam. At the same time, the ICF system measurement method has gradually developed to indirect measurement method. First, the direct measurement method of laser far-field focal spot diagnosis is introduced [3].

2 Related Work

2.1 Laser Far-Field Focal Spot

SHWS is used on the laser device to reconstruct and PIB measure the distribution the target point. The working principle is shown in Fig. 1. The laser is divided into the main beam and the sampling beam through the spectroscop. The main beam is incident into the interior of the target and focused. The sampling beam is incident into the laser parameter diagnosis system. The near-field wavefront phase is measured by SHWS, and then the far-field focal spot intensity of the laser is calculated by Fourier transform. This method makes up for the traditional direct measurement method, which is easily affected by the aberration of additional optical elements and the dynamic range of the detector. However, due to the frequency response characteristics of SHWS itself, the wavefront information of the full frequency band is lost to varying degrees, which affects the measurement [4]. At home, Duan Yaxuan of the and the gave the spatial frequency response model of the SHWS wavefront measurement system. On this basis, he proposed a wavefront reconstruction method with optimized frequency response characteristics, which greatly improved the wavefront measurement accuracy in the middle and high frequency band of the measurement bandwidth, and further improved the accuracy of laser diagnosis.

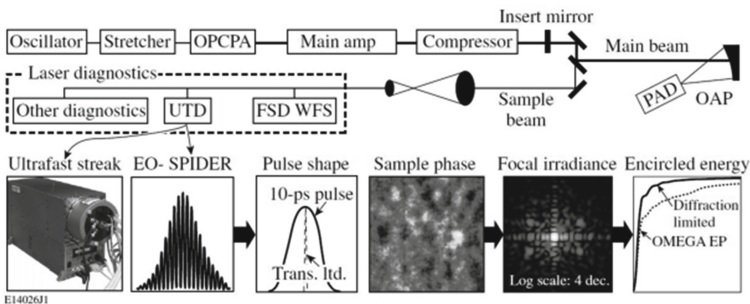


Fig. 1. Working principle of laser far-field focal spot

The light field to be measured diverges after being focused by the lens and is transmitted to the focal plane, and then the CCD receives the diffraction intensity modulated by the random phase plate. Finally, the light field distribution at different positions can

be obtained through the phase recovery algorithm. The field results and at different defocused positions. Keep the low, medium and high frequency information of the focal spot to the greatest extent, and avoid the shortcomings of the direct measurement method or the loss of high frequency information in the measurement of Shack-Hartman wavefront sensor [5]. However, how to improve the convergence speed of the iterative phase recovery method and realize the high-precision diagnosis of the energy is still a problem to be solved at present.

2.2 Laser Beam Characterization

The two-dimensional light field in the object plane can be expressed as:

$$E_1(x_1, y_1) = \rho_1(x_1, y_1)e^{i\phi(x_1, y_1)} \quad (1)$$

among $\rho(x_1, y_1)$ represents the two-dimensional amplitude distribution of the incident field $\phi(x_1, y_1)$ is the phase distribution. Similarly, the outgoing light field of the image plane can be expressed as:

$$E_2(x_2, y_2) = \rho_2(x_2, y_2)e^{i\phi(x_2, y_2)} \quad (2)$$

In the Fraunhofer diffraction and lens focusing model, there is a reversible transformation relationship between the incident light field and the outgoing light field, where the forward transformation is:

$$E_2(x_2, y_2) = F[E_1(x_1, y_1)] \quad (3)$$

Reverse transform to:

$$E_1(x_1, y_1) = F^{-1}[E_2(x_2, y_2)] \quad (4)$$

In phase recovery, amplitude distribution $\rho(x_1, y_1)$ and $\rho(x_2, y_2)$ is known, GS algorithm uses multiple iterations to solve the unknown phase distribution $\phi(x_1, y_1)$ and $\phi(x_2, y_2)$. The iterative process is shown in Fig. 2 below.

1. Initialize the randomly, and synthesize the incident light field with the known amplitude distribution $\rho(x_1, y_1)$ and the random initial;
2. The phase of the incident light field is calculated by Fraunhofer diffraction (F transform);
3. The output light field is synthesized from the new phase in the previous step and the known output light field amplitude distribution $\rho(x_2, y_2)$;
4. The is calculated by the inverse transformation of the outgoing light field through Fraunhofer diffraction;
5. The incident light field is synthesized from the new phase in the previous step and the known amplitude distribution $\rho(x_1, y_1)$ of the incident light field;

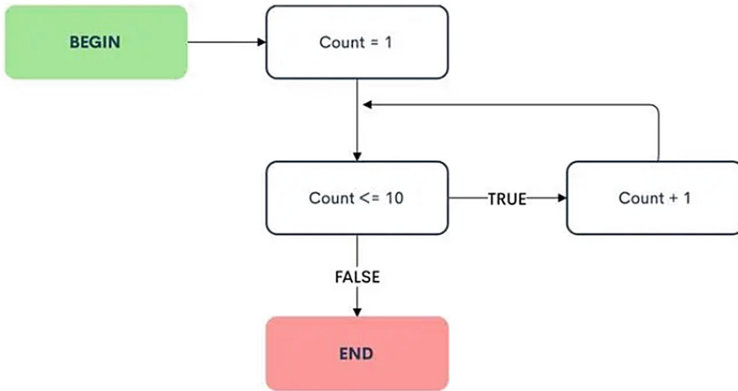


Fig. 2. W Iterative process

3 Laser Far-Field Focal Spot Based on Multi-step Phase Recovery

GS algorithm is of great significance in the development history of phase recovery. This algorithm uses the known light intensity distribution and the frequency domain plane to solve the unknown n of the object plane to be measured by alternating projection and the frequency domain plane. However, GS algorithm is very easy to stagnate and has poor convergence. GS algorithm is the earliest iterative phase recovery algorithm, and subsequent iterative phase recovery algorithms such as ER and HIO are improved and derived on the basis of GS algorithm. Therefore, the principle of iterative phase recovery is introduced based on GS algorithm. According to the amplitude constraints and the frequency domain plane, the GS algorithm uses to iteratively calculate the phase to be measured in the object plane. Because the algorithm uses the detection light intensity of the object and the domain plane to constrain, it is a dual-intensity phase recovery algorithm. As shown in Fig. 3 below, it is a focused light field phase ray recording.

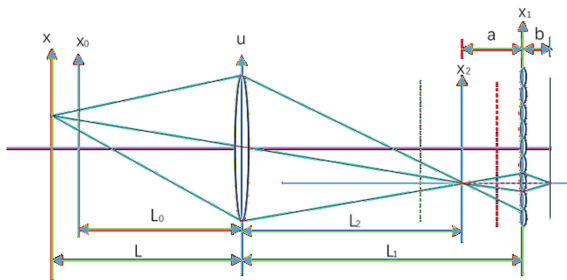


Fig. 3. Focused light field phase ray recording

The physical means is to obtain multiple detection light intensities. Compared with the single iteration of GS algorithm, the single iteration of physical means includes multiple amplitude replacement on different detection surfaces and the constraint of phase reservation, while the single iteration of GS algorithm only performs one amplitude replacement on one detection surface and the constraint of phase reservation. Among the existing iterative phase recovery methods, the common physical modulation methods include multi-range modulation, stacked scan modulation and random phase modulation.

In the single-beam multiple-intensity phase recovery method, the CCD is translated several times to obtain n different diffraction intensities. The single iteration of the method contains several different amplitude constraints, while the single iteration of the GS algorithm only contains one amplitude constraint. Therefore, the introduction of physical modulation into the phase recovery method can effectively accelerate the convergence of the iterative phase recovery method. Similar to the convergence proof of GS algorithm, the convergence of single-beam multi-intensity phase recovery method can be proved as follows.

In the k -th iteration of the single-beam multi-intensity phase recovery method, the objective function can be written as the following general formula:

$$E_k = \sum_{i=1}^n \frac{1}{2} \|\rho_{AS}[U_0(x_0, y_0), z_i]\| - \sqrt{I_i(x_i, y_i, z_i)}\|^2 \quad (5)$$

The subscript i represents the i th transmission distance or diffraction intensity, a total of n diffraction intensities, and the subscript k represents the k th iteration, representing the Frobenius norm.

4 Simulation Analysis

In this simulation, the detection step size is $Az = 5\text{mm}$ and the number of detection steps is $n = 10$. In that the can optimize the distance parameters, on the basis of the theoretical distance values, the recovery results of the proposed and SBMIR method are simulated respectively under five sets of range error values $oz = \pm 0.1, \pm 0.2, \pm 0.3, \pm 0.4$ and ± 0.5 mm. When error is $8z = \pm 0.1\text{mm}$, it distance guess, a disturbance (<102) is guess. For method, the convergence results of all simulation iterations after 100 times are compared with PE-SBMIR method. For method, the evolution $t.ma = 100$, a population contains $K = 20$ individuals, and the quantum bit number of each gene $m = 20$. During the whole simulation process, the software used was on a desktop computer with 3.40GHZ central. The shown in Fig. 4 below.

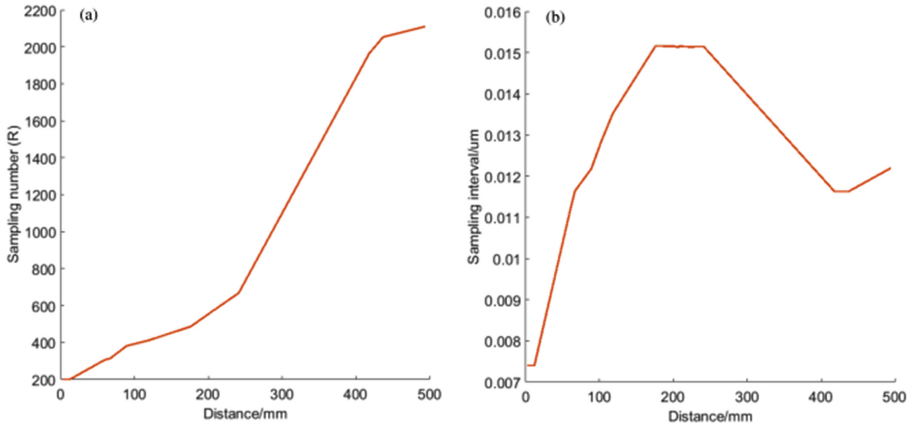


Fig. 4. Simulation result

In this method, the complexity parameter is used to evaluate the difficulty of the recovery of the object to be measured, so the following three requirements are put forward for the known modulation phase: (1) the complexity of the object to be measured needs to be included in the complexity of the known modulation phase; (2) The modulation phase requires continuous distribution; (3) The modulation phase needs to contain different frequency band information. Under the condition that the modulation phase meets the above three requirements, the PRSPM method can quickly converge to solve the object to be measured.

5 Conclusion

Laser beam is a very complex wave phenomenon. The laser beam is composed of light particles, called photons. The wavelength of light determines its color, and its intensity determines its brightness. A single photon has no mass, but it does have momentum and energy. When photons hit an object, some energy is transferred to the object, while some energy is reflected back to the source (photons do not always transfer all energy to the object). This process is called “absorption” or “scattering”, depending on whether they pass through or reflect back from the object. Starting from GS algorithm, the basic principle of iterative phase recovery and the mathematical essence of convergence are described. According to the sampling theorem, the applicable conditions for accurate numerical calculation of diffraction field transmission in frequency domain are derived when the Nyquist sampling interval is satisfied.

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