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Wavefront control of main-amplifier system in the SG-III laser facility

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ABSTRACT

SG-III is a large, 48-beam, high power laser facility mainly for inertial confinement fusion physics experiments. Wavefront distortion is a primary factor decreasing focusability quality of laser beam and impacting secure performance of laser device, and main-amplifier system is one major source of aberrations. Based on the specific configuration of the SG-III main amplifier, two wavefront control approaches are studied, termed as traditional four-pass wavefront correction and novel double-pass wavefront correction. Comparison results show that, both of them are feasible for the wavefront compensation, but double-pass mode is more suitable for our system, mainly because it can make the wavefront distributing more evenly in the different spatial filter pinholes, the high power laser passing through the pinholes more secure and the output beam quality meeting the required performance.

1. Introduction

SG-III laser facility at China Academy of Engineering Physics comprises 48 360 mm square beams. The mission of each beam is to generate a 7.5 kJ, 3 ns laser pulse at 1053 nm by MA (main amplifier, MA) system, convert the infrared beam to a 3.75 kJ, 351 nm laser pulse by potassium di-hydrogen phosphate (KDP) crystal, and deliver it to the target finally [1–3].

Wavefront distortions are common in such high power laser facility, mainly originated from optics fabrication errors, optics mounting stress, location errors of lens and refractive index variation induced by flash-lamps pumping [4–6]. There are two major influences of wavefront distortions. The primary one is to enlarge the focal spot at the spatial filter pinholes and increase the plasma-closure risk [7,8], and the other one is to spread out the far-field distribution at the target, and lower the utilization ratio of laser energy. In order to achieve secure shots and good beam quality required for physics experiments, wavefront distortions must be controlled well. The SG-III subsystems are designed to limit wavefront aberrations. Stringent specifications are determined to constraint the manufacturing optics quality and the optical component mounting. The large aperture optics in the same beamline is chosen based on the measured surface wavefront data to achieve the distortions' self-compensation. As these efforts are effective but insufficient to meet the beam quality requirement of SG-III MA system, an adaptive optics system is absolutely necessary [9–18].

The wavefront control method is dependent on the configuration of the MA system. In the similar laser facilities such as NIF and LMJ [10,12,14,18], the wavefront distortions from front-end to the output pinhole of the MA system is corrected by the DM (defromable mirror, DM) located at far end of the cavity.

In this paper, the wavefront control system in SG-III MA system is introduced. For the special beamline configuration of SG-III MA system, two wavefront control methods are analyzed and compared, termed as four-pass wavefront correction and double-pass wavefront correction. The results show that, double-pass mode is more suitable for our system, because it can make the wavefront distributing more evenly in the different spatial filter pinholes, the high power laser passing through the pinholes more secure and the output beam quality meeting the required performance.

2. The SG-III MA system

A block diagram of the SG-III MA optical system is shown in Fig.1. The pre-amplifier 1ω (1.053 μm) laser pulse is injected into the main laser chain near the focus of the CSF (cavity spatial filter, CSF), and propagates directing towards the DM. The beamline is designed off-axis, and after two-pass of cavity amplifier (AMP1) and one-pass of power amplifier (AMP2), the laser beam will be picked-off into an optical U-turn reverser by a small aperture reflection mirror near the focus of the TSF (transport spatial filter, TSF) [2]. In the U-reverser,

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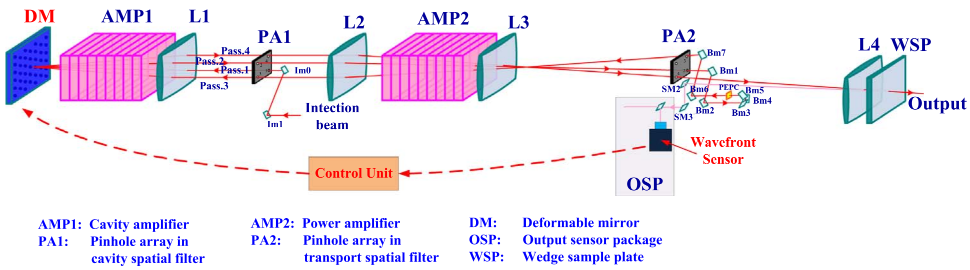

Fig. 1. The block diagram of SG-III MA optical system.

the laser beam near-field is rotated 90° by the "pyramid component" composed by three precisely designed and mounted mirrors. The beam returns into the amplifier chain after U-turn reverser, and then amplified through the power and cavity amplifier again in the pass 3 and pass 4 through the pinholes. At last, the laser is re-collimated by L4, the output lens of MA system, and enters into target bay. In such MA system, the main beamline is not fully symmetrical about DM, and the laser passes through AMP1 four times and AMP2 three times. There are four pinholes in CSF, noted as PA1-1, PA1-2, PA1-3 and PA1-4 in sequence towards laser direction, and also four pinholes in TSF, signed as PA2-1, PA2-2, PA2-3 and PA2-4 accordingly, but PA2-1 is not utilized for the three-pass of TSF. Diameter of pinholes are all 30DL (diffraction-limited, DL) corresponding to the incidence lens and beam aperture.

There are two special characteristics of SG-III MA system, which will influence the detailed design of wavefront control mode. The special characteristics are:

(1) Aperture-alteration

The beam aperture size is changed in different pass by the different focal-length lenses [1]. The beam size is 275 mm×275 mm in the pass 1 and pass 2, and enlarged to 320 mm×320 mm in the pass 3 and pass 4 in AMP1. In AMP2, the beam aperture is 309 mm×309 mm in pass 2, and expanded to 360 mm×360 mm in the pass 3 and pass 4.

(2) 90°rotation

The beam near-field rotates 90° in U-turn reverser. This technology is beneficial to limit the wavefront distortions and mitigate the gain nonuniformity of the plate amplifier [2].

3. Wavefront control system and control methods

3.1. Wavefront control system

Wavefront control system of SG-III MA is shown in Fig. 1, and its functions are implemented as follows. At the TSF output, a tilted sampling surface reflects about 0.2% of the beam towards a sample mirror near TSF focus that sends the sampled beam through relays to the OSP (output sensor package, OSP). In the OSP, wavefront is measured by a 20×20-lenslet HS (Shark-Hartmann, HS) sensor. The HS sensor's video output is read by a frame-grabber in the wavefront control computer. The computer calculates the surface displacements to be applied to the DM to correct the wavefront aberrations in the beam. A 39-actuator large-aperture DM produced by Institute of Optics and Electronics of Chinese Academy of Science, operates at the far end of the laser cavity where the beam bounces twice. The Wavefront control system is calibrated by inserting a wavefront reference fiber source at the last focal point (PA2-4) of the TSF. The reference fiber is single-mode, and smaller than TSF diffraction-limited focal spot, so it could generate a aberration-free light to calibrate the diagnoses beam-path wavefront. The reference focal image in HS is also the target to which the system wavefront is controlled.

3.2. Wavefront oriented control method: Four-pass wavefront correction

Generally, the four-pass wavefront correction method is adopted in the similar laser system, such as NIF, LMJ, and so on [10,12,14,18]. The main laser output by the pre-amplifier is taken as the beacon light of the wavefront control system, and the wavefront from pre-amplifier to PA2-4 could be corrected. The SG-III MA system has the two characteristics of aperture-alteration and 90° rotation, so the main laser beam has corresponding changes between the first and second pass on DM, as shown in Fig. 2. The feasibility of DM surface figure correcting the entire MA system wavefront should be demonstrated firstly.

In such MA system, the laser beam reflects twice on the DM, with 90° rotation and aperture-alteration between the two times, as shown in Fig. 3. By ignoring the correction errors, the beam wavefront could be compensated by

$$-W(x, y) = Dm(x, y) + Rot90\{Ch[Dm(x, y)]\}, \tag{1}$$

where $W(x, y)$ is the entire MA system wavefront, $Dm(x, y)$ is the DM reflection wavefront, $Rot90(*)$ denotes the 90°rotation, and $Ch(*)$ denotes the aperture-alteration.

In the Cartesian coordinates, the relation between beam wavefront and DM reflection wavefront could be delivered as

$$-W(x, y) = Dm(x, y) + Dm(-\sigma\cdot y, \sigma\cdot x), \tag{2}$$

where, σ is the beam aperture ratio between the smaller and larger beam aperture on DM, and $\sigma \le 1$. The Eq. (2) could be written as

$$\begin{aligned} Dm(x, y) = {} & -W(x, y) + W(-\sigma\cdot y, \sigma\cdot x) - W(-\sigma^2\cdot x, -\sigma^2\cdot y) + W(\sigma^3\cdot y, -\sigma^3\cdot x)\ldots \\ & \ldots - \cdots - W(-\sigma^{2n-2}\cdot x, -\sigma^{2n-2}\cdot y) + W(\sigma^{2n-1}\cdot y, -\sigma^{2n-1}\cdot x) + Dm(\sigma^{2n}\cdot x, \sigma^{2n}\cdot y). \end{aligned} \tag{3}$$

By denoting that, $\begin{aligned} h_n(x, y) = {} & -W(\sigma^{2n-4}\cdot x, \sigma^{2n-4}\cdot y) + W(-\sigma^{2n-3}\cdot y, \sigma^{2n-3}\cdot x)\ldots \\ & \ldots - W(-\sigma^{2n-2}\cdot x, -\sigma^{2n-2}\cdot y) + W(\sigma^{2n-1}\cdot y, -\sigma^{2n-1}\cdot x) \end{aligned}$, Eq. (3) could be expressed as

$$Dm(x, y) = \sum_{n=2}^{\infty} h_n(x, y) + Dm(\sigma^{2n}x, \sigma^{2n}y). \tag{4}$$

When $\sigma = 0$, it can be equal to the case that beam is reflected by DM only once, and the DM surface figure for the wavefront correction exists certainly.

When $\sigma = 1$, Eq. (2) could be written as $-W(x, y) + W(-y, x) - W(-x, -y) + W(y, -x) = 0$, so in such case, only some characteristic wavefront satisfying the equation could be compensated by DM.

When $\sigma < 1$, for not clear beam wavefront distortion, $\sum_{n=2}^{\infty} h_n(x, y)$ is convergent from the perspectives of mathematics, and $Dm(\sigma^{2n}x, \sigma^{2n}y)$ becomes flat and can be ignored when $n \to \infty$. So the DM could correct the entire beam wavefront within its ability, and the DM's reflection wavefront can be shown as

$$Dm(x, y) = \sum_{n=2}^{\infty} h_n(x, y). \tag{5}$$

In this MA system, the beam aperture on the DM is 275 mm×275 mm in the first pass, and is enlarged to