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Analysis of the beam-pointing stability in the high power laser system

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ABSTRACT

The far-field distribution is measured by a scientific grade CCD in a single-shot nanosecond-level high power Nd:glass laser system based on a vertical truss structure. The beam-pointing drift of the laser system is analyzed in two methods by calculating the geometric center and the energy centroid of the far-field spots. Results show that the RMS value of the long-term angle drift of the output laser beam is less than 17 μrad.

1. Introduction

The high power solid-state laser system based on the master-oscillator power-amplifier (MOPA) configuration is widely used in many fields, such as inertial confinement fusion (ICF) and generation of intensely thermal X-ray radiation, etc. [1–7]. In MOPA-based high power lasers, spatial filter is an essential component for improving the output beam quality, which is comprised of a focusing-lens and collimating-lens pair with a pinhole placed at their common focus [8–11]. The far-field stability of the laser beam is relative to whether the pulse seed can smoothly propagate through the pinhole and it also contributes to the long-term stable operation of the laser system. If the far-field stability is poor, most of the transmitted energy will no longer pass through the pinhole of the spatial filter. Furthermore, since the Nd:glass rod amplifier has the characteristics of high gain at the edge and low gain at the center, the beam-pointing instability will make the amplified beam instable in the near-field distribution [12]. Meanwhile, the operational instability of the laser system also has an impact on the spatial beam shaping. Therefore, it is significantly to improve the beam-pointing stability.

In recent years, the automatic alignment system has been applied to improving the beam-pointing stability in large-scale high power laser systems [13]. But the automatic alignment systems requires a lot of electrically adjustable mirror frames and near- and far- field CCD working constantly. Hence, the increases of CCD devices add more cost and efforts. As for middle-scale laser systems, such as hundred-Joule-level solid-state laser system, the amounts of complex devices and adjustable devices should be decreased in order to make the system more compact and stable [14]. Therefore, measuring and analysis of the output baem-pointing stability can ensure the beam smoothly transmitting and long-term stable operation of the laser system. Moreover, sources of perturbation leading to pointing instability include the temporally variable thermal

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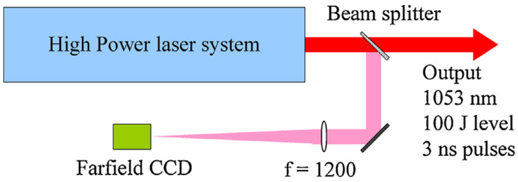

Fig. 1. Schematic of the far-field measurements.

expansion and mechanical vibrations. It is hard to use conventional active beam pointing stabilization techniques based on closed-loop feedback [15] for a single-shot or low-repetition-rate laser system [16]. Because high power laser system always operates at a low repetition, it is effective too ensure the beam pointing stability by a passive technique, such as using a stable mechanical structure.

In this paper, the measurement method of the far-field is introduced, and the far-field distribution of the output beam is measured by the scientific grade CCD, based on the hundred-Joule-level high-power solid laser system in Harbin Institute of Technology. The far-field stability is analyzed by two methods, calculating the geometric center and the centroid of the far-field and then the output beam pointing stability is evaluated. In Section 2, the structure of the laser system and experimental setup is introduced. In Section 3, the far-field stability of the output laser beam is measured. The drift of the far-field is analyzed in two methods by geometric center and the centroid. The high stability of the far-field of the output laser beam provides high assurance for the subsequent frequency conversion and targeting, which lays a solid foundation for the operational stability of the laser system.

2. Experimental methods

The hundred-joule-level laser system has recently been constructed to supply a standard light source for high-energy-density scientific experiments at National Key Laboratory of Science and Technology on Tunable Laser, Harbin [17–19]. This laser system is ideally suited for a wide variety of high-energy-density scientific experiments, including laser-induced damage mechanism for UV optics research [20–22], stimulated Brillouin scattering (SBS) [23–27] and stimulated Raman scattering (SRS) [28,29]. To obtain one beam with an aperture of 60-mm-diameter, the whole size of the laser system is designed to be about 7 m length, 2 m height and 1.5 m width. To mitigate laser damage from particulate contamination at sensitive optics, this lab affords class 1000 clean room conditions throughout with the capability of bringing class 100 conditions to the location of the laser system. The laser system has established on 0.5-m-thick concrete slab foundation that helps to alleviate the general effects of surrounding vibrations. The high power laser system in our lab is supported by a vertical truss [30], and the beam path is on the both sides. Laser components with relatively heavier weight are seated in the bottom of the support frame, such as 100-mm-diameter Faraday isolators and 70-mm-diameter rod amplifiers. As a result of the double-side arrangement of the beam path and consideration of the components' weight of each side the truss configuration can maintain balance.

The experimental setup is shown in Fig. 1. In the high power laser system, there are six rows in the beam path, which has the function of image plane delay, and each row has a spatial filter. The beam path in the spatial filter is sealed in the vacuum pipe that maintains a vacuum environment by the continuous working of the titanium pump. The spatial filter is able to achieve the function of image plane delay, high spatial frequency filtering, beam expanding and isolating reverse laser. At the end of the laser system, the output beam diameter is 60 mm with 100 J laser energy at 1053 nm. The output laser will inject a frequency converter system with two pieces of 14 mm thick KDP crystal for third harmonic generation (351 nm). In our laser system, the half tall full width of tuning angles in the frequency converter system is about 250 μrad [31]. Therefore, the beam drifting angle should be less than this angle to ensure a high efficiency frequency conversion.

When measuring the output of far-field of the laser pulse, a beam splitter mirror (experimental reflectivity $R(1\omega) = 0.86\%$) is applied to separate a part from the main beam path. Then the sampling laser beam transmits through the focal lens f ($f = 1200$ mm) and is focused on the far-field scientific grade CCD camera (GYD-SG1024B12GA CCD) with 1024 × 1024 pixels and 13 μm pixel size each. In order to make the pulse attenuate to the affordable energy of the CCD, several bandpass filters and attenuators are installed in front of the CCD, which can reduce the interference of the stray light. During the experiment, we adjusted the position of the far-field CCD so as to make the laser pulse propagate through the focal lens and focus on the far-field CCD. After that we fixed the posture of CCD.

In our laser system, the output laser beam is nearly spatial flat-top with 3 ns super-Gaussian pulse duration [14,32,33]. After measuring the farfield in experiment, the far-field divergence angle [34] can be calculated as following,

$$\theta = \frac{d_0}{f} \tag{1}$$