Laser beam automatic alignment in multipass amplifier

Daizhong Liu
Jianqiang Zhu
Renfang Xu
Dianyuan Fan
Chinese Academy of Sciences
Shanghai Institute of Optics and Fine Mechanics
National Laboratory on High Power Laser and Physics
P.O. Box 800-211
Shanghai 201800, China
E-mail: dzhliu@mail.shcnc.ac.cn

Abstract. A laser beam automatic alignment system is applied in a multipass amplifier of the SG-III prototype laser. Considering the requirements of the SG-III prototype facility, by combining the general techniques of the laser beam automatic alignment system, according to the image relayed of the pinholes in the spatial filter, and utilizing the optical position and the spatial distribution of the four pinholes of the main spatial filter in the multipass amplifier of the SG-III prototype, a reasonable and optimized scheme for automatic aligning multipass beam paths is presented. It is demonstrated on the multipass amplifier experimental system.
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1 Introduction

The inertial confinement fusion facility is the largest and most complex of high-power lasers, such as the Nova laser, the National Ignition Facility, the GEKKO-XII laser of Japan, the LMJ project of France, and the SG-III facility of China. These lasers, propagating from the master oscillator driver to the target, interact with more than 100 near-field optics and pass through several spatial filter pinholes over a distance exceeding 100 m. To ensure the accuracy of these laser systems, the beam automatic alignment system has been installed on all of them. It has become an important and absolutely necessary part of this kind of laser.

With the development of the laser fusion facilities, beam paths increase greatly. The components have also doubled. Thus, improving the accuracy and shortening the adjustment time in aligning laser beams have became urgent. For example, the alignment system of the National Ignition Facility, which has 192 beam lines, has greatly changed in terms of the design concept and the realization techniques.[1,2] The positioning accuracy for beams on target is given as 50 μm. The pointing accuracy is 6.5 μrad (focal length is 7.7 m). To meet the beam alignment requirements of the SG-III prototype facility,[3,4] based on the multipass beam paths in the amplifier, a reasonable scheme for the beam automatic alignment system was optimized. It was confirmed on the multipass amplifier experimental system. All the beam adjustments can be accomplished in 15 min. The adjustment precision of the near field is less than 0.5% of the beam diameter. The pointing accuracy is less than 14.3 μrad (focal length is 2.1 m).

2 Principles and Techniques

The position of optical components is fixed to achieve a properly adjusted laser system. However, temperature changes, mechanical frame distortion, and output light excursion from the master oscillator all can cause the beams to deviate. Thus, it is necessary to readjust the beam lines before a new shot of the laser system. The main mission of the beam automatic alignment system is to obtain the centering and pointing errors of the beams and to null the beam displacement. All the beam lines are adjusted from the master oscillator to the target. To accomplish these tasks, the beam automatic alignment system uses the general techniques of choosing the alignment light source and the alignment references, obtaining the error information (include centering and pointing), and designing the automatic closed-loop control program.

2.1 *Light Source*

There are two options in choosing the light source for alignment: the first is the laser system's own master oscillator; the second is designing another special laser for alignment. The first option was chosen in the later experiment. The second option requires another laser to couple to the main beam path.

2.2 *References*

Usually some optical element such as a lens on the beam line is chosen as a near-field object. Then its geometrical center is called the near-field reference. The near-field reference, which can be detected by the near-field detection system shown in Fig. 1, determines the beam's centering. The far-field reference is the geometrical center of the pin-

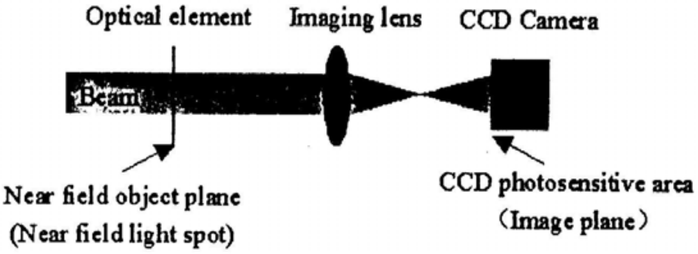

Fig. 1 Near-field beam detection system.

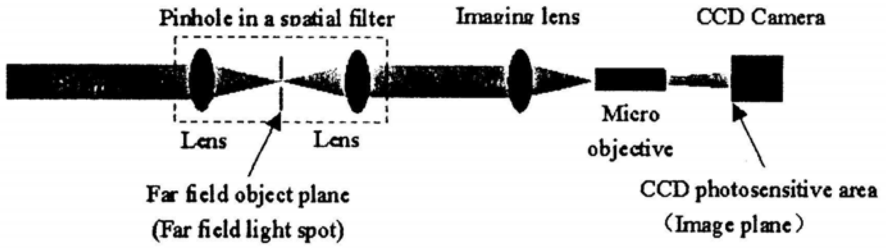

Fig. 2 Far-field beam detection system.

hole of the spatial filter along the beam path, so that the filter pinhole is called the far-field object, which locates in the focal plane of the filter lens. Far-field references, which determine the beam pointing, can be detected by the far-field detection system depicted in Fig. 2. A charge-coupled device (CCD) is used as a detector. The CCD camera records the image center as the beam alignment reference. When a laser beam passes through its two references, the beam's position is correct. Whenever the beam deviates from the alignment references, it can be retrieved through the feedback motion of mirrors using of the error signals.

2.3 *Error Information*

How to pick-up the error information of the beam as well as how to detect the centers of the near-field and the far-field light spots are core techniques of the beam automatic alignment system. The near-field spot is the cross section of the laser beam in the near-field object plane, as shown in Fig. 1. The far-field spot is the cross section of the laser beam in the pinhole plane, as shown in Fig. 2. Because of limited space, the sample beam should be led off the main beam line to be sampled. For example, the light leaking from the reflector mirror can be collected. Then the centers of the near-field and the far-field spots can be detected by the detection systems.

To obtain the near-field spot center, the near-field object should be imaged onto the photosensitive area of the CCD. At the same time, to ensure the adequate precision, the spot image must be magnified to an appropriate size to match the CCD photosensitive area. The CCD we used has 768(H)×576(V) square pixels, and the size (or diameter) of the near-field spot image has over 200 pixels. In detecting the far-field spot, to exactly determine the center of the beam's focal spot, the image of the spot is magnified by a micro-objective to match the CCD photosensitive area. The size (or diameter) of the spot image occupies 30 pixels.

A personal computer (PC) is used to process the collected two-dimensional (2-D) image. The geometrical center of the image can be accurately located if our method, based on Swift et al.,[5] VanArsdall and Reeves[6] and Chen et al.'s[3] considerations, is used. The original far-field (FF) spot is very small, as shown in Fig. 3(a). Thresholding is performed first on the image, as shown in Fig. 3(b), turning on values above the chosen level and turning off values below the level. The result is a binary matrix of 0's and 1's. Next the center of the binary image is calculated, giving the location of the focused spot. By comparing the center of the pinhole and that of the far-field spot, we can obtain pointing error information.

The original near-field (NF) image collected by the CCD is illustrated in Fig. 4(a). First, the median filter is employed to reduce image noise, as shown in Fig. 4(b). Second, the isolated points of the image are removed by the thresholding method, as shown in Fig. 4(c). These techniques improve the quality of the image information and reduce the detection error. Finally, the geometrical center of the image is obtained, as shown in Fig. 4(d). A comparison of two NF images, one of a reference and the other of an alignment beam, provides centering error information.

2.4 *Feedback Controls*

With the pointing and centering error signals, the PC can move the beams to their original positions through feedback adjustment of the motorized mirrors. The detailed flow chart of the process is shown in Fig. 5. In the closed-loop control process, the two motorized reflector mirrors act in turn. But it often happens that one mirror's turning causes the beam light go out of the filter pinhole. Thus, the CCD cannot capture the laser light and the adjustment process is stopped. To solve this problem, this paper proposes a control program that includes small-step, cross-coupled driving methods.

3 Scheme

Based on the techniques and principles already mentioned, aimed at the multipass beam paths on the SG-III prototype laser facility, a unique scheme for automatically aligning the multipass beams was conceived as follows.

3.1 *Multipass Amplifier*

The multipass amplifier system is the principal part of the SG-III facility. Beam paths are evidently different from

Fig. 3 (a) Original FF image and (b) the image after thresholding.

Fig. 4 (a) Original NF image, (b) the image after the median filter, (c) the image after thresholding, and (d) the final image.

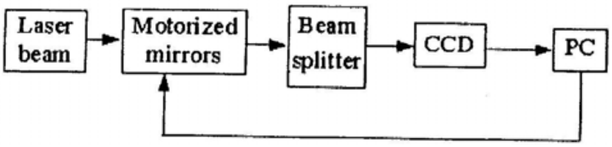

Fig. 5 Closed-loop alignment process.

straight beam paths adopted by previous high-power laser facilities, such as Nova and Shiva. The beams pass back and forth four times through the same amplifier. They must be reflected by the same reflector (the cavity mirror CM) and pass through four different pinholes of the main spatial filter. These factors make the beam alignment more difficult. A sketch of the multipass amplifier system is illustrated in Fig. 6.

The beam coming from the preamplifier system first passes through the lens L0 and then focuses at the pinhole plane, is collimated by lens L1, and is amplified by the magnifying medium. After reflection off the cavity mirror CM, the beam makes a second pass through the magnifying medium. Then it focuses through the lens L1, passes through the pinhole 2, reflects off the reversal mirrors BM1 and BM2, and is collimated as the parallel light by lens L2. After getting across the optical switch, the beam returns back to the spatial filter 1. It makes its third pass through the pinhole 3 in the focal plane of lens L2. After being collimated by lens L1, the third-pass beam returns through the amplifying medium. Then it reflects a second time off the CM, and makes a final pass through the amplifying medium. The beam enters the spatial filter through lens L1, proceeds through pinhole 4, and finally exits as a collimated light beam through lens L3.

The difficulties of the beam alignment are as follows. First, in space, the spatial filter has no room to install the detection systems, the alignment sample light cannot be picked up from the back of the cavity mirror, which is also a deformable mirror. Second, in these techniques, the position of the cavity mirror is fixed, and if it is not accurate, the whole beam paths cannot be correctly aligned, whatever other reflector mirrors are adjusted.

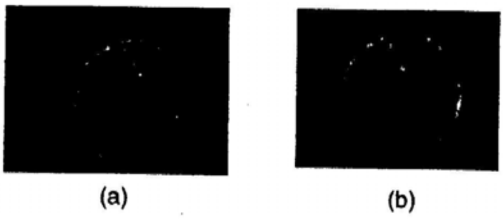
(a) (b)

Fig. 7 Image (a) before and (b) after adjusting the cavity mirror.

3.2 *Automatic Alignment Scheme*

The multipass amplifier contains several pairs of relay images.[7,8] First, the cavity mirror images itself in the multipass beam path. Second, pinholes 1 and 2, located in the pinhole plane symmetrically, constitute a pair of conjugate images; pinholes 3 and 4 form another pair of conjugate images as well. Third, the pinhole plane and the cavity mirror plane are located at the two focal planes of lens L1 respectively. Based on the characteristic of the image relaying, a simple and fast-adjusting design for the beam automatic alignment was worked out. Two NF detection systems and two FF detection systems are required. The cavity mirror CM is adjusted first. Then the first-pass and the second-pass beams are aligned. Finally, the third-pass and the fourth-pass beams are adjusted. The detailed method is as follows.

To adjust the cavity mirror, the detection system of the FF, FF12, is set behind the reversal mirror BM2. The center of pinhole 2 is set as the FF reference. The beam light passed through pinhole 2 and is focused in the CCD photosensitive plane. At the same time, this focal plane must be the conjugate imaging plane of pinhole 2. Since pinholes 1 and 2 are conjugate, and both have the same size, the pinhole 1 image must be relayed to the CCD photosensitive area of FF12. Thus, the cavity mirror CM can be adjusted conveniently before the first and the second passes are aligned. A negative lens FM is inserted in front of reflector mirror IM4 to cause the emanating light to illuminate the pinhole 1. It can be examined to determine whether the image of pinhole 1 is located exactly inside pinhole 2. Fig-

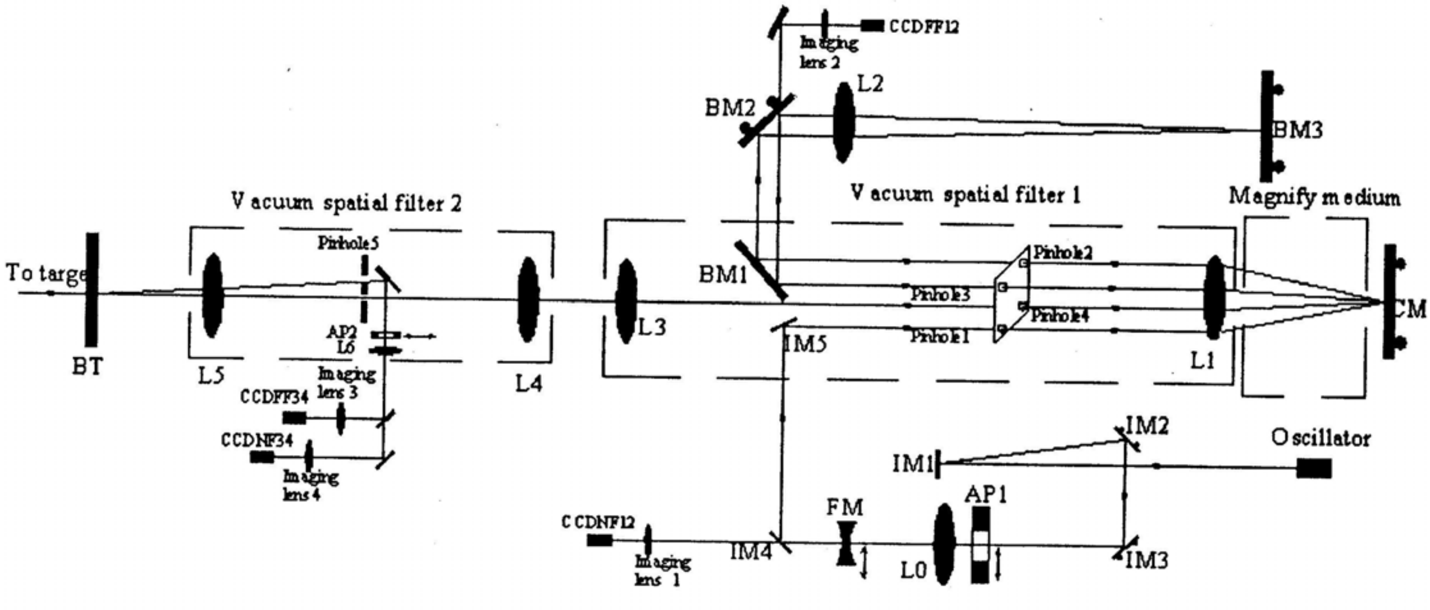

Fig. 6 Sketch of the multipass amplifier system.

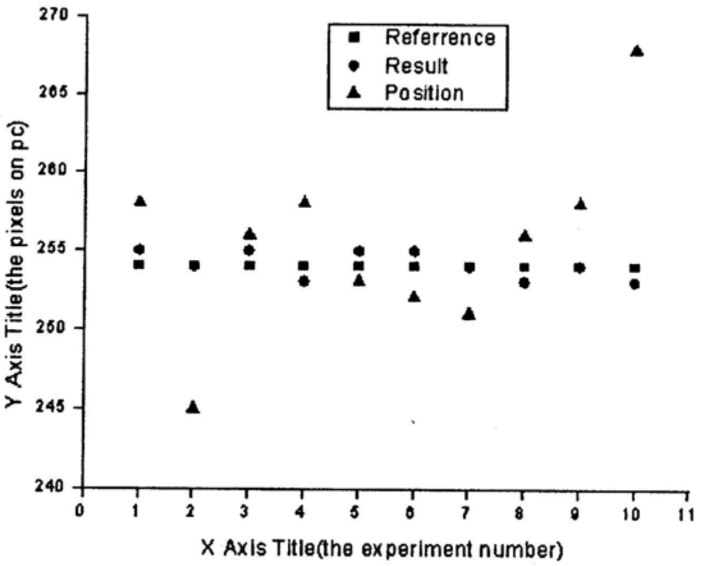

Fig. 8 Experimental results of the beam alignment.

ure 7(a) shows that the image of pinhole 1 was intercepted by the pinhole 2 while the cavity mirror CM was not correctly aligned. But the motors on the cavity mirror can be driven to cause the pinhole 1 image to move exactly on the center of pinhole 2. Then there was a symmetry and circular image on the CCD of the FF12, as shown in Fig. 7(b). The results indicate that the cavity mirror was correctly adjusted.

To align the first and second passes, the detection system of NF12 was set behind reflector mirror IM4. Aperture AP1, the NF reference for the input beam, was inserted at the center of beam before L0. The NF and FF error information was obtained through the detection systems of NF12 and FF12. Then a computer caused mirrors IM2 and IM3 to move to steer the injected beam to pass through the pinholes 1 and 2. Thus, the first and the second passes were well aligned. The following methods were used to verify the alignment results. A piece of paper, which is a transparent material with a pattern of opaque and clear squares, was inserted in the NF beam so as to generate a fourfold symmetric diffracted light pattern in the pinhole plane. As pinhole 2 was viewed through the CCD, it was divided into four equal parts by a cross hair. There was no scatter light at the two sides of the pinhole baffle. All of them showed that the beam passed through the pinholes 1 and 2 exactly.

In aligning the third and fourth passes, the detection systems of NF34 and FF34 were set behind collimating lens L6. The center of pinhole 5 in the vacuum spatial filter 2 was set as the FF reference. Aperture AP2, the NF reference for the output beam, was inserted at the center of beam before L6. The reversal mirrors BM2 and BM3 were adjusted so that the beam could pass through pinholes 3 and 4 accurately.

The main characteristic of the scheme was aligning the cavity mirror conveniently without any sample light picked out at its back. The scheme can easily align the cavity mirror accurately, while no other special light sources are inserted into the main beam path. Four passes can be adjusted rapidly through only two pairs of NF and FF detection systems.

4 Experiments and Results

Experiments were performed on the multipass amplifier experiment system. The beam adjustment of the multipass amplifier system can be accomplished in 15 min. The precision of the NF adjustment was less than 0.5% of the spot. The accuracy of the FF adjustment was 14.3 μrad. To verify the repeatability of the beam alignment, the beam adjustment was repeated every half hour. The results are shown in Fig. 8. For these measurements, the beam was controlled to the same CCD pixel address only 10 times. The triangular points in the figure are positions of the FF beam before alignment. The rectangular points are positions of FF reference. The circular points are positions of the FF beam after alignment. In the experiments, the FF spot had a less than ideal intensity profile with its details changing in time due to gas motion in the propagation path. The pointing accuracy is about 30 μm (focal length is 2.1 m).

5 Conclusions

Considering the spatial distribution and the optical location of the pinholes in the main spatial filter in the multipass amplifier, and utilizing image relaying, the paper optimized a reasonable scheme for automatic alignment of the beams in the multipass amplifier. It was confirmed in the multipass amplifier experiment system.

Acknowledgments

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Daizhong Liu received his BS degree in mechanics in 1995 and his MS degree in 1998 from Xi'an Jiaotong University. He is now a doctoral student with the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. His research interests include laser techniques, image processing and fine mechanics.

Biographies and photographs of the other authors not available.