Design and performance of a video-based laser beam automatic alignment system

Daizhong Liu (刘代中), Renfang Xu (徐仁芳), and Dianyuan Fan (范滇元)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences,
National Laboratory on High Power Laser and Physics, Shanghai 201800

Received November 5, 2003

A laser alignment system is applied to a high power laser facility for inertial confinement fusion. A design of the automated, close-loop laser beam alignment system is described. Its function is to sense beam alignment errors in a laser beam transport system and automatically steer mirrors preceding the sensor location as required to maintain beam alignment. The laser beam is sampled by a sensor package, which uses video cameras to sense pointing and centering errors. The camera outputs are fed to a personal computer, which includes video digitizers and uses image storage and software to sense the centroid of the image. Signals are sent through the computer to a stepper motor controller, which drives stepper motors on mirror mounts preceding the beam sampling location to return the beam alignment to the prescribed condition. Its optical principles and key techniques are given. The pointing and centering sensitivities of the beam alignment sensor package are analyzed. The system has been verified on the multi-pass amplifier experimental system.

OCIS codes: 220.1140, 040.1520, 350.2660.

The inertial confinement fusion laser facilities are large and complex, such as the Nova laser, the National Ignition Facility, the GEKKO-XII laser and the SG-II facility etc. These laser beams propagate from the master oscillator to the target through more than 100 near-field optics and several spatial filter pinholes over a distance exceeding 100 meters. To ensure the accuracy of these laser systems, the beam automatic alignment systems have all been installed on them. For example, the alignment system of the National Ignition Facility, which has 192 optical paths, has greatly improved the pointing sensitivities to less than 6 μm[1−3]. An automated, close-loop, laser beam alignment system is designed and applied to the SG-II facility and the multi-pass amplifier experiment system. The 8 beam paths' adjustment can be finished in 30 minutes in the SG-II facility[4]. One beam path's adjustment of the multi-pass amplifier experiment system can be done in 15 minutes. The centering sensitivities of the system are less than 0.5% of the beam diameter. The pointing sensitivities of the system are less than 10 μm.

The objective of this beam alignment system is to sense an alignment error in a laser beam transport optical system and automatically steer mirrors preceding the detection point in a closed-loop control system to return the beam alignment to its reference location. The alignment errors can be introduced by the temperature's changing, the mechanical frame's distortion of mirrors, the excursion of the oscillator's output beam and some others. Thus it is needed to readjust the beam paths before the new shot of the laser facility, as depicted in Fig. 1.

The main objective of the beam automatic alignment system is to inspect the centering and pointing errors of the beams. Then the beams can be removed to the old location by adjusting a pair of motorized mirrors. The beam path is adjusted from head to foot until it reaches the target. The beam automatic alignment system includes several important techniques as follows: choosing the beam references, obtaining the beam's parameter information (include processing the image signal), designing the automatic close-loop controlling program.

Two centers of beam sections spaced over some distances along the beam path were selected as the references. Beams can be adjusted to the references according to the geometrical principal that two points decide one line. The adjustment precision of motorized mirrors' one step lies on the distance between two points. To ensure the sufficient adjustment precision, the distance has to be long enough, but the space is limited. So a near field point and a far field point were set up. The far field point is equivalent to the infinite distance on optics. The geometrical center of some optic element on the beam path was chosen as the near field reference. The far field reference was set up on the geometrical center of the pinhole of the spatial filter along the beam path, and that the filter pinhole was located in the focal plane of the filter lens. A charge coupled device (CCD) camera was used as the detector sensor. The CCD records these two points' location as the beams references. Whenever beams

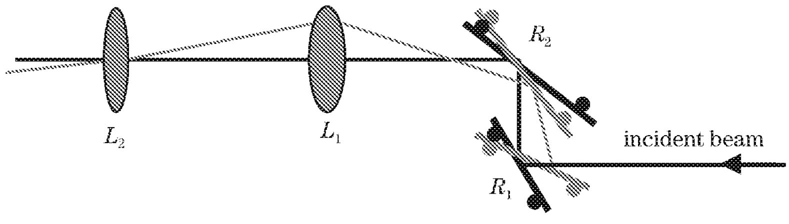

Fig. 1. Adjusting a laser beam.

1671-7694/2004/020092-03 http://www.col.org.cn

deviate from the alignment references, they can be retrieved through the feedback adjustment of a pair of motorized mirrors with the help of the error information. Then the laser beams pass through the two references and the beam lines are at their old location. So the beams are aligned all right.

It is the core technique for the beam automatic alignment that how to pick-up the parameter information of beams as well as how to detect the positions of the near field beam and the far field beam. At first the detected beam must be led off the main beam path so as to be measured by the CCD. The CCD in the alignment sensor package collects the laser beam leaked from the mirror. Then the positions of the near field and the far field can be detected by the detection system shown as Figs. 2 and 3.

The CCD dimensions on the commercial camera which we use are 6.4 x 4.8 mm^2, corresponding to a 811 by 508 pixel arrays. As a worse case, the minimum detectable image shift on the sensor would then be $d_{\min} = 4800$ μm/508 pixels $\approx$ 10 μm. To detect the near field beam, the near field beam should be imaged onto the photosensitive area of the CCD. At the same time to detect the whole beam, the near field image must be minified to the appropriate size to match the CCD photosensitive area. In the alignment sensor package, the near field image occupies about 200 pixels. It can be deduced that the detection precision of the near field is 1/200 of the beam diameter. So the centering sensitivity is 0.5% of the beam diameter. The dimensions of far field images are the same as those of the filter pinholes, which are 3mm in diameter. The image's pixels are 300. So the pointing sensitivity is 10 μm.

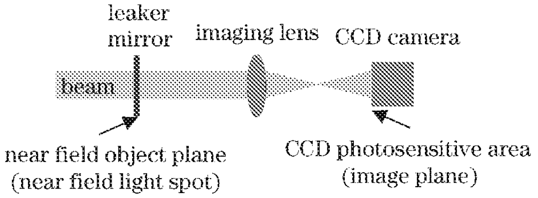

Fig. 2. Detection system of the near field.

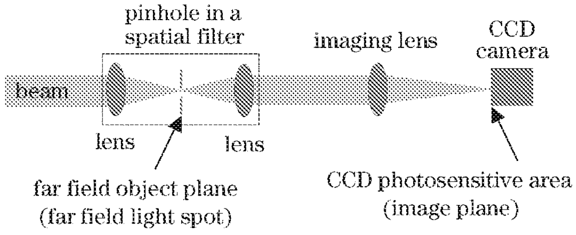

Fig. 3. Detection system of the far field.

To get the error information, a computer should process the collected two-dimensional image. The geometric center of the image can be accurately located if the method was used, as explained in Ref. [5]. The original image collected by the CCD is illustrated as in Fig. 4(a). At first, the median filter was employed to reduce image noise, shown in Fig. 4(b). Secondly, the isolated points of the image were gotten rid of by the threshold method, shown in Fig. 4(c). These techniques improve the quality of the image information and reduce the detection error. At last, the geometric center of the image was obtained, shown in Fig. 4(d). After obtaining the centers of the near field beam and the far field beam, the desirable error information can be obtained by comparing these centers' information with the references locations.

According to the error information of the near field and the far field, the beams can be returned to the reference locations through the feedback adjustment of a pair of motorized mirrors by a computer. The detailed flow chart is shown in Fig. 5. The major components of the beam alignment system include:

1) Leaker mirrors that provides the alignment diagnostic beam;

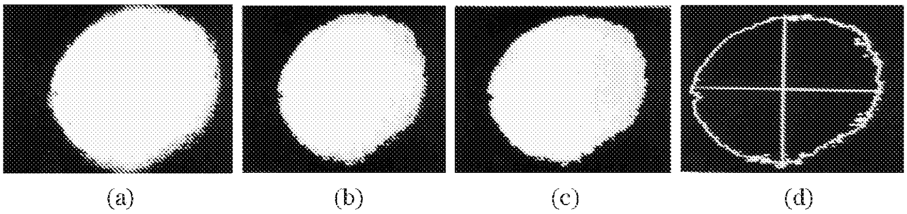
(a) (b) (c) (d)

Fig. 4. (a) Original image; (b) after median filter; (c) after threshold; (d) the last image.

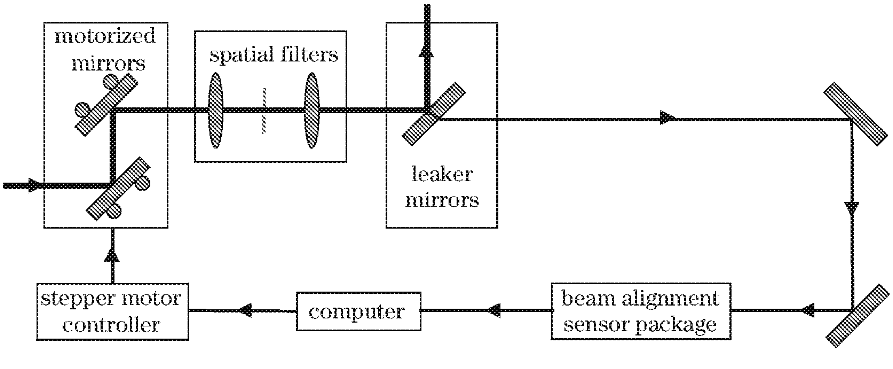

Fig. 5. The alignment close-loop.

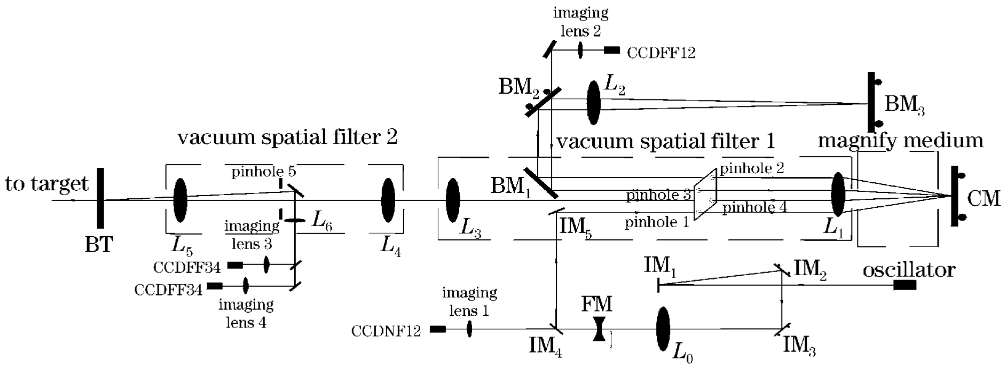

Fig. 6. Sketch of the multi-pass amplifier system.

2) Near field references and far field references;

3) Motorized control mirrors;

4) Beam alignment sensor packages capable of imaging the diagnostic beam onto CCD cameras preceded by at least two turning mirrors to direct the diagnostic beam into the sensor package;

5) Computer, to process video images and generate error signals;

6) Stepper motor controllers for the motorized mirrors.

In the close loop controlling process, the two mirrors act in turn. But it often happens that one mirror's turning makes the beam go out of the spatial filter's pinhole. Thus the CCD cannot capture the beam and the adjusting process is stopped. In the NIF beam alignment system, the filter pinholes are first moved out of the beam path, and then the alignment adjustment is done, at last the pinholes are restored. Our controlling program uses small-step and stepwise moving methods to solve those troubles.

The alignment system has been applied to the SG-II facility and the multi-pass amplifier experiment system. The automatic alignment system of the multi-pass amplifier experiment system is shown as Fig. 6. The beam adjustment of the multi-pass amplifier system can be finished in 15 minutes. The precision of the near field adjustment was less than 0.5% of the beam diameter. The sensitivity of the far field sensor was less than 10 μm.

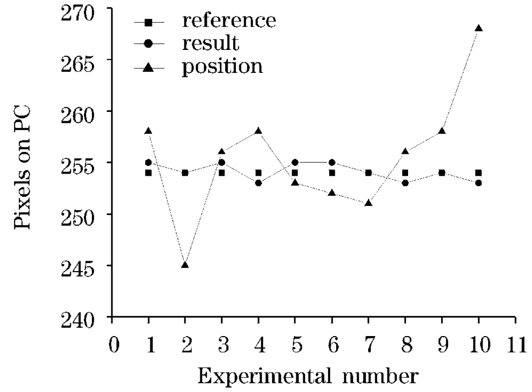

Fig. 7. The alignment results of the far field beam.

To verify the repeatability of the beam alignment, the beam adjustment of the multi-pass amplifier experiment system was repeated every half an hour. Figure 7 shows the results of ten continuous experiments. The triangle points are positions of the far field beam before aligning. The rectangle points are positions of the far field reference. The circle points are positions of the far field beam after aligning.

In conclusion, a laser beam automatic alignment system is designed. Its optical principles and key techniques are introduced. The alignment sensitivities are analyzed. The system has been applied to the SG-II facility and the multi-pass amplifier experiment system. One beam path's adjustment can be finished in 15 minutes. The centering sensitivities of the system are less than 0.5% of the beam diameter. The pointing sensitivities of the system are less than 10 μm.

This work was supported by the auspices of the National 863 Project (863-804-5). The authors would like to express thanks to the Laser Fusion Research Center of CAEP for the supports in the experiment. D. Liu's e-mail address is dzhliu@mail.shcnc.ac.cn.

References

1. S. J. Boege, E. S. Bliss, C. J. Chocol, F. R. Holdener, J. L. Miller, J. S. Toeppen, C. S. Vann, and R. A. Zacharias, Proc. SPIE **3047,** 248 (1997).
2. F. R. Holdener, E. Ables, E. S. Bliss, S. J. Boege, R. D. Boyd, C. J. Chocol, D. T. Davis, R. D. Demaret, R. E. English, C. W. Laumann, J. L. Miller, and S. W. Thomas, Proc. SPIE **3047,** 692 (1997).
3. J. A. Paisner, J. D. Boyes, and S. A. Kumpan, Proc. SPIE **2633,** 2 (1995).
4. D. Z. Liu, Q. H. Chen, R. F. Xu, W. Y. Liu, Z. Y. Peng, H. B. Yang, and C. L. Zu, Laser & Optoelectronics Progress (in Chinese) **38,** 85 (2001).
5. Q. H. Chen, R. F. Xu, Z. Y. Peng, C. L. Zu, and Y. F. Zhuang, Acta Opt. Sin. (in Chinese) **15,** 531 (1995).