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Evolution of Shiva Laser Alignment Systems

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Abstract

The Shiva oscillator pulse is preamplified and divided into twenty beams. Each beam is then amplified, spatially filtered, directed, and focused onto a target a few hundred micrometers in size producing optical intensities up to 10^{16}W/cm^2. The laser was designed and built with three automatic alignment systems: the oscillator alignment system, which aligns each of the laser's three oscillators to a reference beamline; the chain input pointing system, which points each beam into its respective chain; and the chain output pointing, focusing and centering system which points, centers and focuses the beam onto the target. Recently the alignment of the laser's one hundred twenty spatial filter pinholes was also automated. This system uses digitized video images of back-illuminated pinholes and computer analysis to determine current positions. The offset of each current position from a desired center point is then translated into stepper motor commands and the pinhole is moved the proper distance. While motors for one pinhole are moving, the system can digitize, analyze, and send commands to other motors, allowing the system to efficiently align several pinholes in parallel.

Introduction

Shiva's twenty beams must be accurately aligned in a timely fashion in order to irradiate several microscopic fusion targets per day. Figure 1 is a line diagram of the entire laser system with the major alignment components identified. The beam starts at

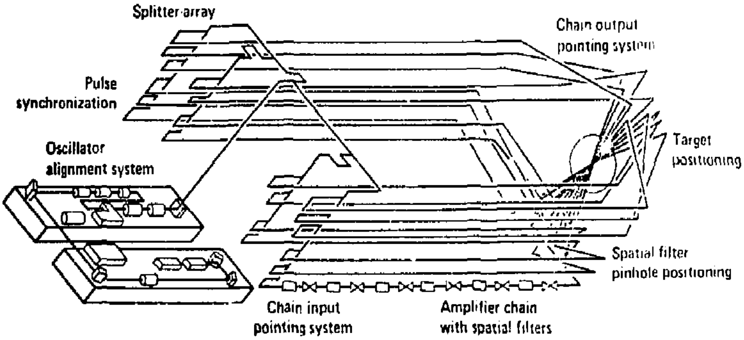

Figure 1 Shiva laser system

the oscillator where it is aligned by the oscillator alignment system. The beam is then preamplified and split into twenty beams in the splitter array. At this point each beam is pointed down its chain by the chain input pointing system. Each chain is approximately 50 meters long and consists of amplifiers separated by spatial filters. The spatial filter pinholes are aligned using a sensor at the output of each chain. The beams are then directed by two large aperature turning mirrors to the final focus lenses and onto the micro-target. The alignment of the turning mirrors and focus lenses are accomplished with the chain output pointing system.

The automatic alignment systems can be divided into two types. The original alignment systems, which include the oscillator alignment system, the chain input pointing system, and the chain output pointing system, are characterized by local microprocessor control with a lateral-effect photodiode for error detection.[1] The second type is the new automatic pinhole alignment system which uses the vidicon television cameras for error detection and the control room alignment computer for control. This paper will explain how the original, and the new automatic alignment systems on Shiva work.

Original alignment systems

Oscillator Alignment System (OAS)[2]

There are three oscillators on Shiva. The pulsed oscillator supplies the pulse that is used on system shots. A CW mode-locked laser supplies a train of pulses that is used to set the optical path length of each arm so that pulses from all twenty beams arrive at the target at the same time. Finally, a CW laser chopped at 630 Hz is used by the automatic alignment systems and the vidicon TV cameras to monitor beam position. Since the laser and target alignment is done with the CW oscillator and the system shot is taken with the pulsed oscillator, the OAS must co-align the oscillators very accurately.

The multi-oscillator alignment is accomplished by aligning all oscillators to the same reference, the oscillator alignment sensor. The reference beam line is established using one detector for pointing and one detector for centering. A beam splitter samples the main beam line, and in the case of the pointing detector a lens focuses this sampled beam onto the face of the detector. In the case of centering detector a lens images the beam profile in front of the splitter onto the face of the detector.

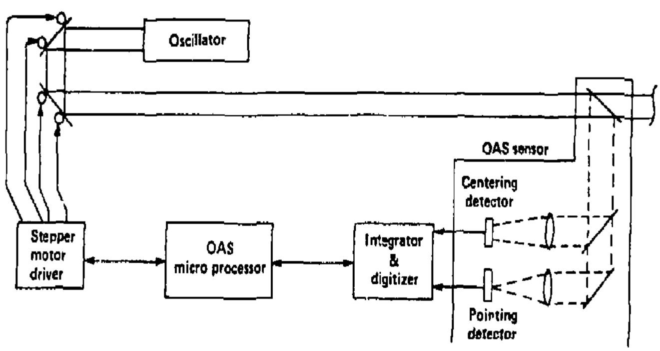

Figure 2 Oscillator alignment system

Figure 2 is a line diagram of the oscillator alignment system. Alignment errors are sensed on the lateral-effect silicon diodes. The signals are intergrated and digitized before being transmitted to the microprocessor. The microprocessor calculates and displays the error and at the same time sends the error corrections to the stepper motor driver which in turn moves the beam steering mirrors.

Chain Input Pointing System (CHIP)

The CHIP sensor at the input of each chain is used to measure beam angular errors with respect to the chain of amplifiers and spatial filters. The chip detector is bolted directly to the spaceframe so that its relationship to the amplifiers and spatial filters remains constant.

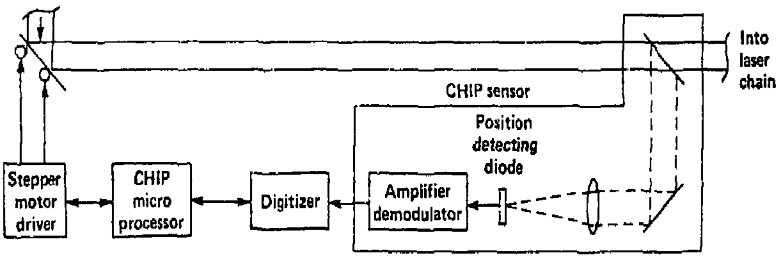

Figure 3 Chain input pointing system

The operation of the CHIP is similar to the OAS except that it only corrects pointing errors and it only works with the chopped CW oscillator. Figure 3 shows how the beam is sampled and brought to a focus on the detector. The chopped error signal from the lateral-effect silicon diode is amplified and demodulated. The signal is then digitized in a microprocessor which calculates errors and corrections for the display and stepper motor driver.

Chain Output Pointing System (CHOP)

The CHOP sensor is located behind the final turning mirror of each beam and has three principle modes of operation: the centering mode, which is used to center the beam on the final focusing lens; tne pointing mode, which is used to point the beam onto a surrogate target; and the focus mode, which is used to adjust the distance between the final focusing lens and the surrogate target. Only the centering and pointing modes were designed for automatic alignment.

In the centering mode a retroreflector is remotely inserted in front of the final focus lens. The plane of this reflector is then imaged in the CHOP sensor onto a lateral-effect silicon diode. Since the CHOP sensor and target chamber are both mounted on the spaceframe, the sensor diode provides a reference for beam centering. The error signal from this diode is processed in the same way as the CHIP diode signal as illustrated in Figure 4. The microprocessor calculates appropriate motor movements for the two mirrors to change centering without changing the pointing.

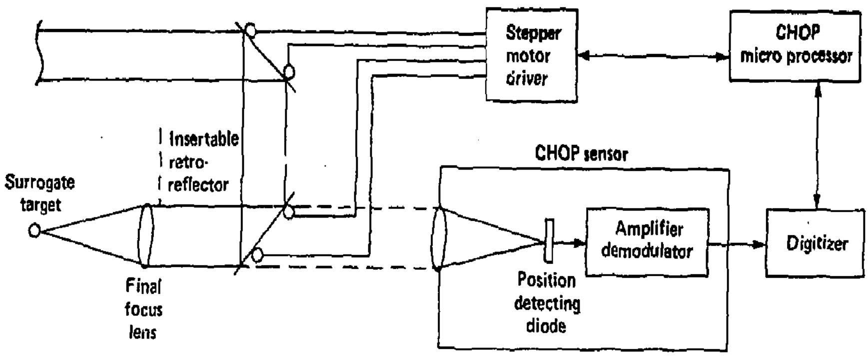

Figure 4 *Chain output pointing system*

In the pointing mode a gold plated 5 mm diameter spherical surrogate is aligned to the center of the target chamber using two orthogonal target viewers. Now the incident beam is focused by the final focus lens onto the gold sphere and retroreflected into the CHOP sensor and onto the diode. If the central ray of the incident beam is perpendicular to the surrogate target the offset as seen by the CHOP sensor will be zero, whereas for even a few microradians of angular misalignment an offset will be observed. Error signals generated by this offset are processed just like centering error signals but only the final turning mirror is moved to correct pointing errors.

New alignment system

Spatial filter alignment

While the OAS, CHIP, and CHOP were designed and built as part of the Shiva project completed in early 1978, the automatic spatial filter alignment system was added in late 1979. This system automates a task which was initially done manually and required two operators working about one hour. Now it takes approximately 30 minutes, and only one operator is required to handle any problem that occurs.

There are 120 vacuum spatial filters in Shiva, six in each of the 20 chains. A spatial filter consists of a two positive lenses placed at the distance equal to the sum of their focal lengths with a pinhole placed at the common focus. The pinhole is used to block light that is not traveling in the same direction as the main beam. This off-angle light is generated by optical imperfections and enhanced by self-focusing. It is therefore very important to position the pinhole so that the main beam passes through while the off angle light is intercepted by the pinhole.

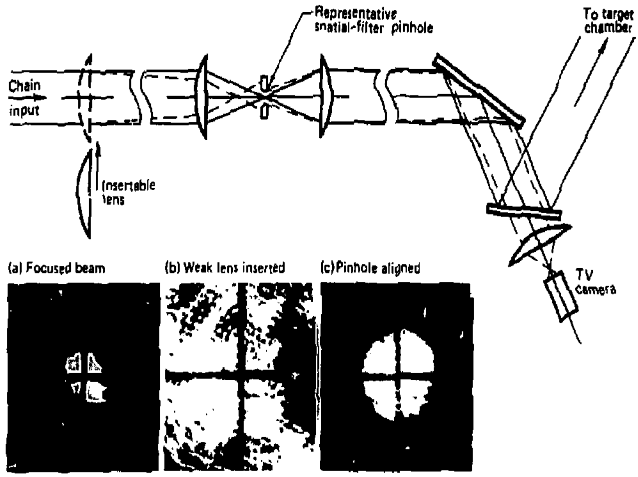

Figure 5 Spatial filter pinhole alignment

The pinhole alignment scheme used on Shiva is illustrated in Figure 5 for one chain. The incident beam diagnostic (IBD) sensor is behind the final turning mirror and contains optics and a TV camera to view the spatial filter focal plane. With all of the stepper motor driven pinholes removed, the image of the focused spot is aligned to a reference cross hair in the IBD package. Next a weak lens is placed in the beam at the beginning of the chain. The weak lens causes the beam to focus ahead of the spatial filter pinhole plane and then expand to fill the entire IBD field of view in the pinhole plane. Now the pinholes are moved one at a time into the beam and aligned to the reference cross hair. The inset photos in Figure 5 show the TV image of the beam as seen on the control room monitor for each step. As each pinhole is aligned, its position is recorded in an LSI-11 micro processor, and the pinhole is removed. The next pinhole in the chain is then aligned. When all of the aligned pinhole positions have been recorded, all pinholes are moved to their recorded aligned positions and the lens at the beginning of the chain is removed.

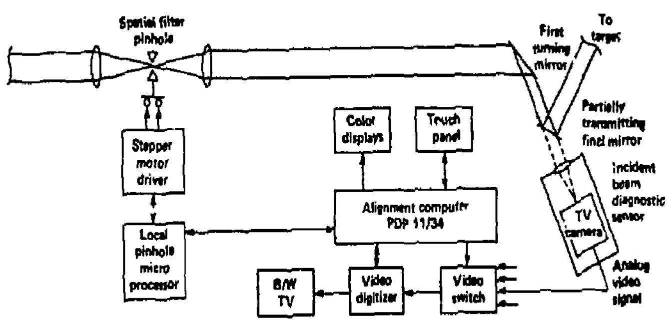

Figure 6 Automatic spatial filter alignment system

Automation of this alignment scheme was made possible by the addition of a video digitizer linking the Shiva TV network to the alignment system's PDP 11-34 minicomputer.[3] Figure 6 is a block diagram of the components relevant to the automatic pinhole alignment. Operator commands are entered via a touch panel mounted over a computer driven display panel. The status is displayed on color displays. One channel of the video switch is controlled by the PDP 11-34 computer and its output is fed to the video digitizer. The digitized video is analyzed and the size of the required pinhole motions is transmitted to the LSI-11 microprocessor which controls each pinhole positioner motor. As pinhole alignment proceeds, processed images are sequentially displayed on TV monitors in the control room so that the operator can verify proper system performance.

Figure 7 and 8 are processed images of a focused beam and a back-lighted pinhole. The software required for this system consists of programs for image analysis, plasma panel control, video selection, color status displays, executive control, and video digitizer control.

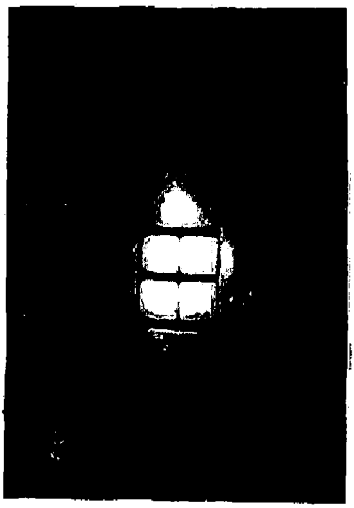

Figure 7 Analized focused beam

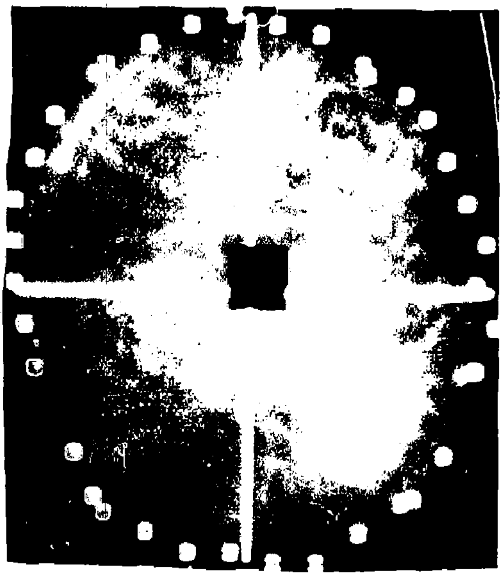

Figure 8 Analized back-illuminated pinhole

The software for image analysis is divided into focused spot analysis and pinhole analysis. The focused spot is much brighter than the background and it is therefore possible to take the centroid of all intensities over a background level and get the correct position. Figure 7 is a photo of an analyzed focused spot. The pinhole analysis is much more difficult because the contrast is lower and the illumination is nonuniform. To overcome these difficulties a edge detection algorithm is used. The image is scanned in a horizontal and vertical direction noting the edge crossings. The distance between these edge crossing is then compared with a stored value to see if it is a valid pinhole. The small dots on the edge of the pinhole in Figure 8 represents these valid edge crossings.

Conclusions

The automatic pinhole alignment system, which uses a television vidicon for error detection, has major advantages over the original alignment systems which use lateral-effect photodiodes for error detection: it isn't limited to calculating the centroid of the beam intensity because it can be programmed to identify beam edges, for example; background rejection can be done more reliably; and the image alignment and quality on the vidicon are easy to verify by viewing a television monitor. These advantages have made the automatic pinhole alignment system so successful that we are considering the use of video techniques in other system control functions on Shiva. Video systems will also form the basis for all alignment control functions on the Nova laser system now under construction.

Acknowledgments

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