7

CONF-8404124--4

NOTICE

UCRL--90033

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

DE84 010992

NOVA LASER ALIGNMENT CONTROL SYSTEM

Paul J. Van Arsdall
Frederick W. Holloway
David L. McGuigan
Randy T. Shelton

This paper was prepared
for submittal to the
Technical Symposium East '84
Arlington, Virginia
April 29 - May 4, 1984

March 29, 1984

MASTER

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

ms
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Nova Laser Alignment Control System*

Paul J. Van Arsdall
Frederick W. Holloway
David L. McGuigan
Randy T. Shelton

Lawrence Livermore National Laboratory
P. O. Box 808, MS L-492
Livermore, California 94550

Abstract

Alignment of the Nova laser requires control of hundreds of optical components in the ten beam paths. Extensive application of computer technology makes daily alignment practical. The control system is designed in a manner which provides both centralized and local manual operator controls integrated with automatic closed loop alignment. Menudriven operator consoles using high resolution color graphics displays overlaid with transparent touch panels allow laser personnel to interact efficiently with the computer system. Automatic alignment is accomplished by using image analysis techniques to determine beam reference points from video images acquired along the laser chain. A major goal of the design is to contribute substantially to rapid experimental turnaround and consistent alignment results. This paper describes the computer-based control structure and the software methods developed for aligning this large laser system.

Introduction

Nova is a large pulsed laser facility that supports Inertial Confinement Fusion (ICF) research at Lawrence Livermore National Laboratory (Fig. 1).¹ The latest in a series of increasingly energetic neodymium-glass laser systems at Livermore, Nova's ten 74 centimeter diameter beams will concentrate 100-150 terawatt of optical power onto an experimental fusion target and the resulting physics data will be studied. Pulse lengths of 100 picoseconds to 3 nanoseconds are possible. Just prior to the final focusing lens at the

*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

target chamber, potassium dihydrogen phosphate (KDP) arrays inserted in the beam path double or triple the fundamental 1.06 micron light for irradiation experiments at three wavelengths. Nova is scheduled to begin full operation in the last quarter of 1984.

Operation of a complex electro-optical-mechanical system such as Nova requires a sophisticated control system with an easily understood man-machine interface. Because laser operating staff are unable to be both technical specialists and also control system experts, this interface must be easy to master. Since the Nova ICF facility supports a robust experimental program using the latest in instruments, configurations and methods, the control system must also be easy to change. Approximately 5,000 control and data acquisition points are distributed over a large area making centralization necessary for effective coordination of target shots. These factors strongly influenced the design of the systems described in this report.

Functionally, the control system is organized into five major parts.² Four subsystems correspond to major areas of the laser system. The first, power conditioning, actually fires the laser and orchestrates much of the timing for the other subsystems. Some 40 million amperes of current at 25 kilovolts flow at each target shot. A laser diagnostic subsystem monitors the laser optical performance for preshot setup and gathers data for postshot analysis. A target diagnostic subsystem records data generated by a variety of instruments for physics analysis of the fusion target implosions. The fourth subsystem, alignment, is concerned with transporting the laser beams and focusing them on targets, some as small as 500 microns in diameter. A central control system unifies and coordinates the other four.

The control subsystems are organized around a medium scale distributed computer network based upon three centralized Digital Equipment Corp. VAX-11/780 computers with over 50 smaller LSI-11 computers located near the laser hardware (Fig. 2). The LSI-11s provide the major system interface and substantial standalone local control capability. The VAX computers run software which integrates the operation of the facility via interactive color graphics based operator consoles on which programmable menu style controls are drawn. There are four identical consoles in the master control room, each with three high resolution Ramtek 9400 graphics displays (Fig. 3). The center screen is overlaid with a transparent touch input system. To select a function, an operator simply touches a button or schematic symbol with his

finger. The two side screens display system status. The layering of menus permits a massive amount of information to be presented in a small working area by providing only the necessary functions for any given task at a particular time.

Efficient, reliable intercomputer communications are essential to any real time distributed control system. Nova relies on a large multiport memory shared between the VAX computers to coordinate all high level activity. Important data and command messages maintained in this memory allow programs in any of the VAX computers to access system wide information. The LSI-11 computers are tied to the central VAX computers and to each other via an in-house designed local area network (LAN) Novanet.³ The LAN operates at 10 megabits per second over serial fiber optic links for immunity from noise in the pulse power environment. In use, operator response times of fractions of a second are realized for command functions originating at the control console and performed in a distributed LSI-11 somewhere in the system.

Alignment control system

The alignment control system must accurately steer the ten Nova laser beams, each covering a path of 250 meters, from the master oscillator to the fusion target. Stepping motor actuated electro-mechanical devices interfaced to 29 LSI-11 microcomputers are employed to monitor and control the alignment of the laser. Figure 4, which depicts only one of the ten laser arms, illustrates the magnitude of the alignment task. Mirrors are adjusted to center the beams at the beginning of each laser section and subsequently to point the beams through to the next section. Seventy-seven spatial filters in the ten arms relay the beams between laser amplifiers and remove destructive intensity modulation from the beam. A tiny pinhole in each spatial filter must be accurately positioned to allow the focused beam to pass through. Finally, alignment of all ten beams to the fusion target at any of the three operating wavelengths must be accomplished. In all, over 200 automatic alignment loops need to be closed by the control system. In addition to the actively aligned components, a large number of devices provide reference information and control energy distribution in the laser chains.

Experience gained from the smaller two beam Novette laser, operational with a proto-type alignment system since late 1982, has clearly shown the

importance of adequate controls not only for operation of the facility during target experiments but also for component installation during the construction phase. Proper beam alignment in the front end is necessary for establishing the positions of downstream laser components. To be of assistance in the early stages, the control system must be sufficiently modular to allow parts of the laser to operate normally while other sections are still being built.

Digital processing of sensor images is used to close the loop for automatic alignment. Figure 5 illustrates a typical alignment loop for aiming the laser beam toward the target. Multifunction sensors are strategically located along the laser path which view the beam and insertable reference crosshairs. The sensors generate video images in a standard television format which are digitized and then analyzed by an array processor attached to the VAX. Commands sent to the appropriate LSI-11 move the mirrors to the proper position. In case of manual alignment, computer analysis is replaced by operator judgment and either local or remote manual computer control.

Verification of alignment is straightforward because the video images are directly observable by operators on convenient television monitors. Closed loop alignment systems developed in the past have incorporated more simple detection schemes such as those employing silicon quadrant cells. The reliability of such systems is difficult to monitor routinely. Image analysis techniques for reference determination are proving to be insensitive to intensity variations and other anomalies such as partially blocked beams. Confidence tests have been developed which ensure the automatic alignment system will not misalign the laser even under the less favorable conditions experienced in a facility under construction.

Figure 6 shows a block diagram of the interrelated components of the alignment control software. Three major software programs are unique to operation of the alignment system, shown in the box "VAX application programs." Two of the main programs service the operator console. System configuration and manual controls are implemented by the Console Alignment Program (CAP). One copy of the program is active for each console in use. Independent graphic displays showing system status are maintained by the other program. Automatic alignment of the laser beam is accomplished by a third independent program. The graphics system is a common software utility which

interfaces these programs to the human operator through the console hardware. A graphic frame library contains definitions for the menu controls and status displays.

The three programs communicate through memory shared between the three VAX computers and among the various programs. Signaling for synchronization of memory access is done with interlocking functions supported by the VAX operating system. Note that the alignment programs need not be resident in the same VAX. Indeed, for Nova, the automatic alignment program normally runs on one VAX while the operator station controls are coresident with the laser diagnostics control subsystem on another VAX.

Stepping motor controller

The microcomputer based Stepping Motor Controllers (SMC), serve as the primary alignment control building blocks. The SMC is capable of economically controlling up to 60 stepping motors and 16 two-state "binary" channels. SMC control commands originate from either a local control panel or from the upper level computers over Novanet. SMC units are assembled from a common hardware repertory (Fig. 7) and software system. Each application is specified by software tables in the SMC and the VAX. Eight different SMC configurations are needed for Nova with common definitions shared among parallel chains.

Basic to the SMC design is the concept of an alignment "device." A device is a collection of stepping motors strongly related in alignment function. For example, a pair of 2-axis mirrors forms a four motor device called a "gimbal." A typical binary device is a shutter with open/shut verification switches. Devices may be uniquely reserved for use by an application program in the central computers in a manner analogous to allocating a disk drive or other computer resource. This mechanism prevents conflicts resulting from two or more programs or operators attempting to use components for dissimilar tasks at the same time.

The device approach permits customization of the local control panel and remote commands. Instead of fixed labels on control panel switches, programmable alphanumeric 18-segment displays are configured to reflect the function of each switch. Each device selected for panel control is customized by the display of a meaningful name, for example, "MID-CHAIN GIMBAL," as well

as appropriate labels for the slew axis controls. The programmable nature of the local control panel minimizes errors by prompting the operator and is much more flexible to changes than a fixed panel design.

Primary functions available to the operator and programmer are SLEW, GOTO LIMIT, DECLARE SETPOINT and GOTO SETPOINT. Setpoints are previously determined motor positions used, for example, to return to previous alignment conditions or to select filters from a turret wheel. GOTO LIMIT is used to position devices, such as crosshairs, against a hard stop where positive feedback from a switch is needed. Multiple groups of devices may be commanded with special operator programmable functions. These functions allow complex configuration of many optical elements at once. This is used for selecting sensor modes or for setting up a beamline for an often repeated task.

The status of each device is displayed on the control panel and returned to the central computers on demand. Current positions referenced to ten declarable setpoints and the condition of end of run limits is returned. Optional position verification is accomplished by adding incremental encoders. Since alignment components are sometimes removed for repair, disconnected device control cables are detected and reported to the central control system.

Installation and maintenance of large components in difficult-to-access areas makes using rack-mounted control panels for alignment cumbersome. Although several technicians with the help of walkie-talkie communication can effect most operations with some effort, geographical separation of the SMC and components interfere with adequate feedback between equipment and operator. A special pendant controller provides the same operator controls as are found on the SMC. Several such pendants may be attached to the central computer system by plugging them in to convenient RS-232 serial ports located throughout the facility. Any alignment device in the system may then be used in support of the maintenance job at hand while directly observing mechanical response.

Most of the alignment devices in the Nova system can be handled by medium torque motors at relatively low speeds. However, large apertures near the end of the laser chains involve physically large and heavy components. Additionally, laser operation at multiple wavelengths require long range focusing adjustments. The final focus lens, for example, is subject to 12,000 pound vacuum loading from the target chamber and must be adjusted over a ten million motor steps operating range.

Outboard equipment is used to interface these exceptional applications to the control system. Medium range, high torque devices are powered by inserting current boosting amplifiers in series with the ordinary drive channels available for smaller stepping motors. Long range, high torque devices need to be positioned at much higher speeds up to 5,000 steps per second to avoid extraordinary long adjustment times. Commercially available Superior Electric Modulynx (tm) stepping motor controls were integrated into the SMC logic to provide this high performance capability. All of these motor options may be mixed as necessary to characterize alignment generic devices based upon system requirements and not upon lower level interface specifications.

Application of the SMC in Nova required several special design considerations. For one, motor power is applied only during actual positioning in order to reduce thermal loading of the optical environment. Secondly, all signals in or out of the SMC are optically isolated to prevent ground loop induced noise from affecting the data acquisition systems which monitor laser and target performance. Backlash correction is needed to automatically remove positioning errors introduced by the mechanical hardware. Because the laser path is folded and does not always lie in a plane, crosscoupling transformation from the motor coordinate system to the video sensor coordinate system is necessary. The transformation yields an equivalent X-Y motion as observed by the operator viewing the television monitor in response to X-Y positioning commands.

Operator station controls

The user interface at the central control console brings the distributed components of the alignment system together in a manageable manner. Operator control displays are drawn on the center Ramtek screen. Access to the system is layered from general to specific by traversing a tree of graphic touch input menus. Figure 8 illustrates the four level hierarchy. At the topmost level, an alignment subsystem is selected from several geographically and functionally distinct areas. Menu choices at the second level perform semi-automatic setup functions, determine access to manual controls and initiate automatic alignment sequences. At this stage, appropriate status displays are requested on the two side screens. Level three menus are

schematic representations of portions of the laser which allow touch selection of devices for manual control (Fig. 9). Simple two-state device controls such as CROSSHAIR: IN/OUT are available directly at this level but controls for more complex devices such as sensors and gimbals are accessed at level four.

The task selection menus at level two offer commands for moving large groups of devices to a predefined setup. The tasks are defined to configure the system for common alignment activities and to request initiation of automatic alignment. Configuration commands are sequenced to allow setups to be done in a particular order. For example, video cameras are protected by blocking incident laser light before sensors are reconfigured for another function. In addition, status checking of the setup is made to prevent system malfunction. If a device fails to perform properly, the operator enters into an error dialog at the console for further action.

A tutor function at the second level simulates configuration tasks by imitating status on the two side screens. With the tutor, the programmer may debug task definitions or the operator may review a particular configuration without impacting the actual state of the alignment system. The tutor may also be used to help instruct novice staff in the operation of the system.

Access to devices is controlled at level two through the reservation system implemented within the SMC units. In this way, multiple operator consoles and automatic alignment may participate in nonconflicting tasks on the same alignment subsystem. Devices which are available for manual control are colored green on the level three schematic and may be touch selected while nonallocated devices are taken into the background as a grey color and are not available to the operator for manual adjustments.

Manual controls at level four include specific functions and incorporate a force-operated joystick for continuous slewing of device motors. Figure 10 illustrates a multifunction sensor control frame. Functions needed for sensor control are field of view, focusing and neutral density filter selection. Usually, crosscoupling of motor coordinates to sensor coordinates is selected by the operator such that the observed image motion tracks the joystick motion. Detailed status information such as position and limit conditions is displayed directly on the graphics frame.

The force operated joystick simultaneously enters direction and rate in two axes with excellent tactile feedback to the user. The joystick has finer resolution at the slow slewing rates in order to ease making small adjustments. Up to eight joysticks are serviced by a special LSI-11 microcomputer performing data compaction and by a VAX monitor program which routes joystick values through shared memory to the appropriate operator console software.

The Alignment Status Program (ASP) automatically displays the system status on the two side screens of the operator console as alignment devices are adjusted by the system. Schematic representations of major portions of the laser system are enhanced with color coded symbols which reflect the current status of each alignment device. Most conditions are displayed with solid colors. For example, green is used to indicate a properly aligned component whereas red indicates that an error condition has been detected. Blinking colors are only used for transient conditions or to get operator attention. For example, blinking white indicates a device is currently in motion. In addition to the use of color which quickly summarizes the alignment condition, text augments the symbols for more refined information of device status. Laser gain settings, sensor mode and specific error messages are examples. The device status color key is uniformly assigned to all displays in the alignment system.

Updating of a status display is automatically started when a particular display frame has been requested by the CAP. The appearance and removal of the display is signaled by the graphics system. Upon notification of a frame call-up, the status display program begins to poll the appropriate SMC machines via Novanet to determine the status of the devices that are drawn on the screen. The independent nature of the status display program eliminates the need for either of the control programs to maintain the status frames, thus greatly simplifying the software required. Moreover, any program in the entire control system may simply request an alignment status display to be drawn by the graphics system and the status information will be updated in real time until the frame is removed.

Automatic alignment

The Automatic Alignment Program (AAP) closes pointing and centering loops of the laser beam by adjusting gimbaled mirrors. Apertures and spatial filter pinholes are aligned with methods similar to those employed for aligning

mirrors and will not be discussed specifically. Pointing is the angular rotation of the beam about a single point whereas centering is the parallel translation of the beam path. Once the beam is centered at the beginning of the optical chain, it is then pointed along the path to the next pair of mirrors without further disturbing centering. Sensors in the system are capable of separating pointing and centering information by obtaining far-field and near-field images of the laser beam. The AAP uses image analysis techniques to extract position information from the video picture acquired from each sensor. Corrections are then calculated to align the component and the procedure repeated until errors are within tolerance. The AAP is sufficiently modular to maintain alignment of portions of the system while operators work manually elsewhere.

Additional special hardware is required by the AAP including a video switcher system, a video digitizer, and an array processor. The capability to view any of the 43 alignment sensors in the facility is accomplished with a Telemation TVS-1000 video crosspoint switching system. The switching network is under software control by the VAX, allowing the AAP to select the correct channel. Before the image can be processed, the analog signal must be converted to numerical form. Digitization is done with a Quantex DS-12F video digitizer which converts the video image to a 256 x 256 integer matrix with intensity levels in the range of 0 to 255. The converted image is processed by a Floating Point Systems FPS/120B array processor. The outboard equipment is necessary to accelerate the computationally intensive analysis. Were the calculations to be done solely with the VAX-11/780, the analysis time would be too great for the system to be a viable alternative to manual alignment techniques.

Video scenes captured by the Quantex are preprocessed to ensure consistent image quality. All images are subsampled down to a 128 x 128 pixel format both to reduce storage requirements and to reduce computation time. The resolution obtained is better than 1 percent. Each image is built by averaging several digitized frames together. This helps eliminate slowly varying noise in the analog TV system. The background, taken under dark conditions, is subtracted from the image to remove effects of any camera imperfections. Next, the image is low pass filtered in two dimensions to reject most spatial high frequency noise. The mean intensity of the image is then calculated and subtracted to yield a clear image with a dark background. A final step checks

the picture for a minimum brightness, thus testing for adequate illumination by the alignment laser beam.

Angular pointing information is seen as X-Y translation on the TV monitor when the sensor is viewing the far-field. The beam, when viewed by a sensor in pointing mode, is a focused bright spot. The spot must be aligned coincident with a reticle on the sensor camera. Since only the beam spot remains in the picture after the background subtraction, anything above a certain intensity level is considered part of the beam spot. Thresholding is performed on the image, turning values above the chosen level on, and values below the level off. The result is a binary matrix of zeros and ones. Next the centroid of the binary image is calculated, giving the location of the focused spot. Only picture elements which are turned on are used to calculate the centroid, greatly reducing the number of calculations. Pointing is most sensitive to alignment drift, therefore these loops are closed more frequently than other alignment loops. The higher loop rate drives the requirement for an efficient location algorithm. With this method, the calculation of the focused spot location is accomplished in less than half a second. Total loop iteration times of a few seconds, including the time necessary for motor positioning, have been realized.

The reference points for centering the laser beam are given by the center of shadows cast from crosshairs temporarily inserted into the beam. To find the location of the center of a crosshair in an image the image is first digitized without any crosshairs in the beam. Then the crosshair is inserted and another image is digitized. Next the image with the crosshair is subtracted from the image without the crosshair. Only the portion of the beam that is blocked by the crosshair remains. The first time this difference image is obtained (during the activation of the alignment loop) the location of the center of the crosshair in the image is identified by an operator and stored in the VAX along with the difference image as a "template." Subsequent difference images, obtained during system operation, are correlated with the template to determine the current location of the crosshair center. There is a unique template stored on disk files for each crosshair image in the system. Crosshair orientation is fixed, so only one correlation measure needs to be computed.

Figure 11, taken from a typical processing run, shows the three analysis steps observed by an operator at the console TV monitor. Part a) is the

crosshair as seen by the sensor camera. This particular crosshair is severely diffracted as a result of being some distance from an exact beam relay plane. Most crosshairs in the system have arms which appear much sharper and have well defined edges, but since the correlation technique depends more on consistent diffraction patterns than edges, this is not a problem. Part b) of the figure shows the difference image. Part b) is then correlated with the reference template by computing the two dimensional fast Fourier transform on each image and then by performing the correlation in the frequency domain for maximum speed. Part c) of the figure shows the resulting correlation function, scaled to fit within the quantization levels of the video digitizer and reordered spatially to restore symmetry about the correlation maximum. The location of the template in the image field is annotated by a square superimposed on the original in Part a).

For most sensors, comparison of two crosshair images is used for determining corrections. One crosshair identifies the beam center, the other is a reference to which the beam should be aligned. In these cases, the above operation is done for both crosshairs one at a time. The centers of the two crosshairs are aligned to be coincident by driving the appropriate gimbal stepping motors.

The AAP operates by reading ASCII command and parameter lists supplied in disk files. Should one or more of the loops encounter an error condition, the analysis is repeated until the error condition is remedied. To perform a different task, a different command list is specified. The AAP continually loops through the command lists until told to stop by the console operator or by a supervisory program. The AAP is particularly adaptable to hardware changes because only the analysis methods are coded directly in software. The file structure also makes parameter adjustments and adding new loops possible without needing to recompile the software.

The automatic alignment system is structured for processing of all ten beams in parallel. A much higher throughput is obtained because analysis can continue on some beams while crosshairs or other components are in motion on adjacent beams. Some additional time is expended reading template and parameter files, but the improvement in flexibility and ease of adjustment more than compensates for this. At the time of this writing, loops have been closed in Nova from the master oscillator to the mid-point the ten laser chains. Typical times of slightly over ten minutes have been realized for

both pointing and centering loops under normal conditions. Corrections in any loop require more time because device motions must be verified by reanalysis.

A graphic status display can be requested which illustrates the current processing states of all loops in AAP. Particularly since the program aligns the ten beams in parallel, an independent view of the alignment loops in progress is an important means of determining when and where operator attention is required. At the start of an alignment cycle all loops which are to be closed (as specified in the command lists) are annotated on the display. As each loop becomes active, the associated loop status symbol blinks white. Upon successful alignment the symbol color is changed to green. An unresolved error condition which generally requires operator assistance is signaled with a flashing red symbol.

The detection of an error condition causes the display of a descriptive error message both on the facility TV system and on the status screen. A loop hold control available on the graphic control menu allows an operator to suspend automatic processing while corrective actions are taken. A typical error condition occurs when, for some reason, a beamline is blocked and insufficient light reaches a video sensor. This condition is readily detected by the AAP, but because of the unpredictable nature of the cause, operator action is necessary to remedy the problem. In the suspended state, the intermediate image analysis results remain visible on the console television monitors. A quick look at the analysis usually suggests corrective action. When conditions warrant continuing the alignment operation, the hold control is released and processing resumes.

Analysis reliability

A common procedure used to verify that the template object has indeed been found in the image field is to compare the maximum value of the correlation function with a minimum reference value recorded under normal operating conditions. The value of the cross correlation is very dependent upon image brightness, however, and use of this test alone would result in excessive failure of many of the analyses in cases of low illumination. Extremely bright but arbitrary images also drive up the correlation maximum value even if the template object is not visible in the image field, thus fooling the minimum value test. Testing the correlation against a minimum value in an

experimental environment is not adequate for ensuring reliability of the analysis.

Since crosshairs must be backlighted by the alignment laser and the crosshair image is formed by using the light in the crosshair shadow, it is possible to have situations where only one of the two crosshair arms is visible at the sensor. These cases can occur under rather severe system misalignment where a preceding component aperture clips the backlighting beam. Noting that each arm of the crosshair image is also a part of the template image, the cross correlation technique finds the center to be in the middle of the arm segment, not at the intersection of the two arms. Careful examination of the correlation function reveals that there are about three times as many points above a fixed threshold for the single arm correlation as there are when part of both arms is visible. This observation leads to a powerful test to ensure accurate crosshair reference detection. The test is performed by comparing the histogram of high valued correlation points to known good values. Typically only a small number of the total 16,384 image points satisfy this criteria. Histograms of two to three times or greater the expected number of points indicates only one arm is visible. It has not been necessary to check the actual shape or spatial distribution of the points although such a step would be even more specific.

Application of this test allows correlations to be accepted over a wide dynamic range with a high degree of confidence. Figure 12 shows two crosshairs and their corresponding correlation functions in which only small parts of the two arms are visible. The information present in the orthogonal arms causes the correlation function to peak sharply. The intersection determination is accurate unless only one arm can be seen. The same test also detects extreme over illumination or component damage effects where excessive numbers of image points have values near the correlation maximum value.

Conclusion

The alignment controls operating on the Nova system are easier to use and expand in the experimental environment than were previous designs. The modularity is sufficient to allow both automatic and manual operations to occur in portions of the facility while other portions are still being installed. Installation efforts are aided by the early deployment of this

system. The application of color graphics to a high level menu driven operator interface improve the alignment control and monitoring of a large optical system. A high degree of automation simplifies the operation of the facility, improves reliability and provides more consistent alignment. These factors combine to reduce the requirements on the laser operating staff, to lower costs and to shorten alignment turnaround time.

Acknowledgments

The authors wish to acknowledge a number of people who have contributed substantially to the work reported in this paper. Robert Boyd helped activate the alignment control system and provided considerable understanding of the optical design; Jerome Krammen developed the interactive graphics system; Craig Humphreys did much of the initial array processor code; John Hill and John Severyn implemented the Novanet communications network; and Gregory Suski designed the overall control system architecture for Nova. The technical guidance and leadership of Erlan Bliss is also greatly appreciated.

References

1. Simmons, W. W., R. O. Godwin, C. A. Hurley, E. P. Wallerstein, K. Whitham, J. E. Murray, E. S. Bliss, R. G. Ozarski, M. A. Summers, F. Rienecker, D. G. Gritton, F. W. Holloway, G. J. Suski, J. R. Severyn, and the Nova Engineering Team (1982). "Engineering Design of the Nova Laser Facility for Inertial Confinement Fusion," Compendium of 11 papers from the Proc. IEEE 9th Symposium on Engineering Problems of Fusion Research, 1981.
2. Hill, J. R., J. R. Severyn, P. J. Van Arsdall, "NOVANET Communications Network for a Control System," in Proc. Eighth Data Communications Symposium, Massachusetts, 1983 (Cape Cod, Massachusetts, 1983).
3. Suski, G. J., J. M. Duffy, D. G. Gritton, F. W. Holloway, J. R. Krammen, R. G. Ozarski, J. R. Severyn, P. J. Van Arsdall, "The Nova Control System - Goals, Architecture, and System Design," in Proc. IFAC Workshop on Distributed Computer Control Systems, Russia, 1982 (Tallinn, Russia, 1982).

FIGURE CAPTIONS

Figure 1. Nova ICF facility.

Figure 2. Nova computer system.

Figure 3. Operator console.

Figure 4. The alignment system directs laser beams by moving more than 1,000 stepping motors.

Figure 5. Digital image processing closes automatic alignment loops.

Figure 6. VAX software block diagram.

Figure 7. The step motor controller interfaces a variety of devices.

Figure 8. Operator controls menu hierarchy.

Figure 9. Schematic device selection menu.

Figure 10. Multifunction sensor control frame.

Figure 11. Crosshair analysis: (a) crosshair image (b) difference image
c) correlation function.

Figure 12. Worst case successful crosshair analysis: (a) sensor image I
b) correlation I (c) sensor image II (d) correlation II.

Van Arsdall - Fig. 1

THE NOVA COMPUTER SYSTEM IS A HIERARCHY OF CENTRALIZED
PROCESSING POWER AND DISTRIBUTED FUNCTIONS

Van Arsdall - Fig. 3

Van Arsdall - Fig. 4

Digital processing of sensor images closes the loop for automatic alignment

Van Arsdall - Fig. 6

Van Arsdall - Fig. 7

THE FRAME TREE PROVIDES FOUR HIERARCHICAL LEVELS
OF CONTROL

02 05 0393 1148

Van Arsdall - Fig. 10

(a) crosshair image

(b) difference image

(c) correlation function

(a) sensor image I (b) correlation I

(c) sensor image II (d) correlation II