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ABSTRACT

Earlier papers have described approaches to NIF alignment and laser diagnostics tasks.[1,2,3] Now, detailed design of alignment and diagnostic systems for the National Ignition Facility (NIF) laser is in its last year. Specifications are more detailed, additional analyses have been completed, Pro-E models have been developed, and prototypes of specific items have been built. In this paper we update top level concepts, illustrate specific areas of progress, and show design implementations as represented by prototype hardware.

The alignment light source network has been fully defined. It utilizes an optimized number of lasers combined with fiber optic distribution to provide the chain alignment beams, system centering references, final spatial filter pinhole references, target alignment beams, and wavefront reference beams.

The input and output sensors are being prototyped. They are located respectively in the front end just before beam injection into the full aperture chain and at the transport spatial filter, where the full energy infrared beam leaves the laser. The modularity of the input sensor is improved, and each output sensor mechanical package now incorporates instrumentation for four beams.

Additional prototype hardware has been tested for function, and lifetime tests are underway. We report some initial results.

1. OVERVIEW OF ALIGNMENT AND DIAGNOSTIC DESIGN

The National Ignition Facility will deliver light from 192 laser beams to a common target. The system is designed to focus 1.8MJ, 20nsec pulses of 351nm light into a 600mm diameter volume every 8hrs. Effective use of this output in target experiment campaigns requires that each beam path be carefully controlled and each beam accurately characterized.

The scope of NIF beam control and diagnostics systems necessary to accomplish this task is unprecedented for laser facilities. Each beam line contains 110 major optical components distributed over a nominal 510m path. There are nearly 600 alignment beams and 1400 alignment references. Approximately 160 sensor packages, 825 CCD cameras, 9500 motors, 250 photodiodes, 215 calorimeters, and 192 wavefront sensors and deformable mirrors complete the principal optical-mechanical hardware. Supporting electronics to drive the component motions are also required.

Successful operation of such a system requires a high level of automation. Operators will oversee system activities, respond to performance exceptions, and complete maintenance tasks. However, the computer control systems provide the basis for completing shot preparations with repeatable accuracy and in a timely fashion.

The tolerances for alignment and beam diagnostics functions are demanding. Table I lists the principal requirements for beam positioning, frequency conversion crystal angle tuning, measurements of pulse energy and power, and monitoring of the spatial profile of beam fluence.

Alignment	
Position each beam in the component apertures	0.5% of the aperture
Direct each beam through the spatial filter pinholes	5% of the pinhole diameter
Control the position of each beam on the target	50mm
Adjust the angle of the final optics KDP crystals	10mr
Beam characterization	
Measure pulse energy at 1.053 and 0.351mm	2.8%
Measure pulse power versus time	4% with 450psec rise time
Record the spatial profile of beam fluence	2% fluence resolution,1/150 of beam spatial resolution

Table I. Tolerances for key alignment and diagnostics tasks

Performance of alignment and beam diagnostic functions is accomplished by optical, electronic, and mechanical components distributed along each beam line. Figure 1 identifies these components and

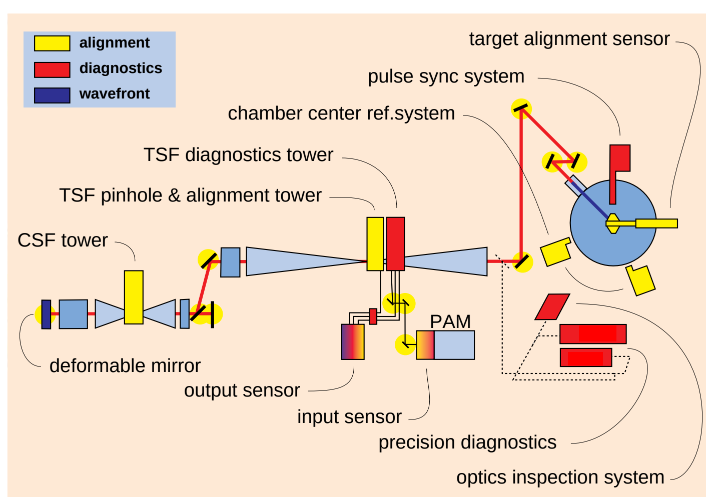

Fig. 1. Optical, electronic, and mechanical components distributed along each beam perform beam control functions. Towers near the pinhole plane of the cavity spatial filter (CSF) and the transport spatial filter (TSF) actually hold components for alignment and laser diagnostics functions on eight beams. In the figure, only one beam line is shown for clarity.

illustrates the fact that the beam control systems have interfaces with every part of the laser. Other papers in these proceedings address the related topics of beam position error budget[4], diagnostic measurements on Beamlet[5], damage inspection system design[6], wavefront correction[7], and integrated control systems[8]. References to wavefront correction components are included in the figure because the output sensor to be described later includes the sensor for closed-loop wavefront control.

2. EXAMPLES OF DETAIL DESIGN

Detailed design of the alignment and beam diagnostics systems is nearing completion. A primary example of this progress is the alignment light-source distribution-network. This network provides both beams and references for alignment, and it comprises four independent subsystems. Three of the subsystems distribute 1.053mm alignment beams, pinhole references, and centering references. The fourth provides 0.351mm beams for alignment to the target. Figure 2 illustrates how the 53 lasers of the light source network are multiplexed to provide signal to 1400 different locations in the system.

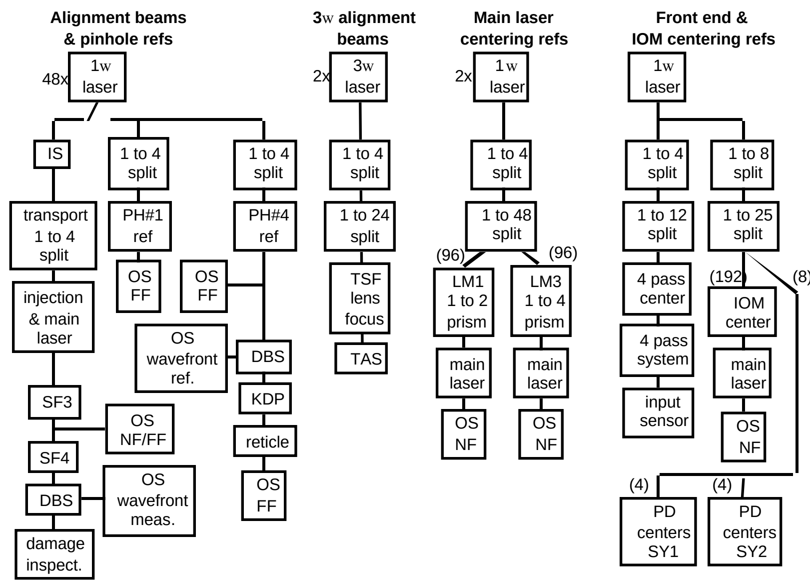

Fig. 2. The light source network provides both beams and references for alignment.

For each light source function there is a specific design to match the size and f/number of the output to the requirement for that function. For example, behind two of the main laser turning mirrors, centering references are specified to have a pair of parallel and approximately collimated beams with a diameter of ~1.5cm. Figure 3 shows

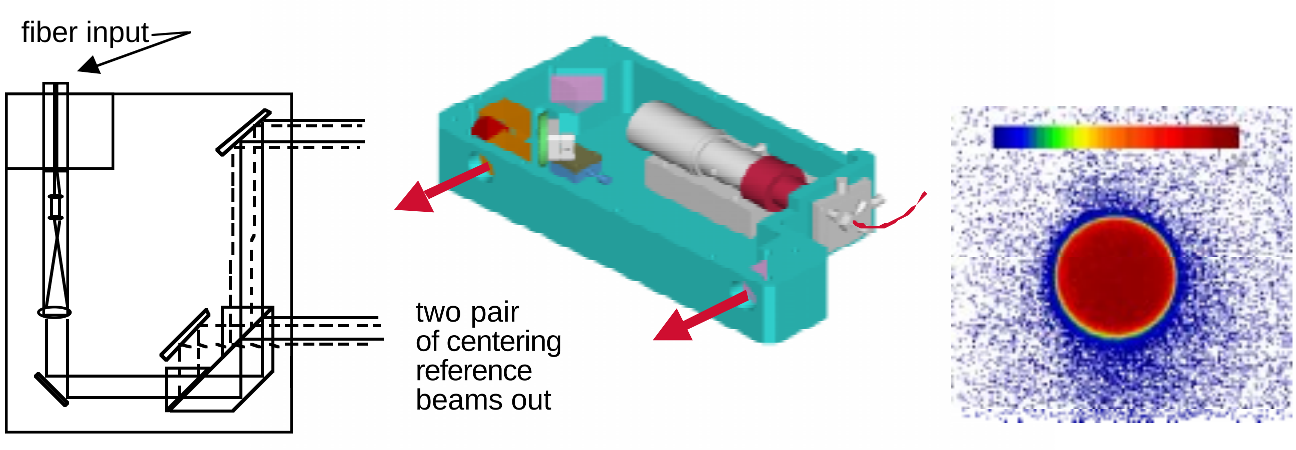

Fig. 3. The centering reference module design (schematic and Pro-E model on left) is simple, and the position of each beam in a CCD image (example on right) is easily determined.

a schematic of the formatting optics at these locations and a Pro-E model of the centering reference module. The light is delivered by a multimode fiber, but speckle in the CCD image is averaged within the video frame time by a continuous perturbation of the fiber.

The input sensor, which is located at the output of the preamplifier module (PAM) as illustrated schematically in Figure 1, has also reached an advanced state of design. Figure 4 shows each side of the sensor package. On the main beam side, components between the preamplifier upstream from the sensor and the relay telescope mounted on the input sensor frame are enclosed in a class 100 clean module. A small fraction of the beam leaks through the first turning mirror and is sent through a window in the frame to the instrumentation side of the package. Two additional input ports are identified on this side of the package. They accept beam samples from the outputs of the regenerative amplifier and beam shaper. The package provides near and far-field video images as well as measurements of power and energy. Because the main beam does not pass through this module, it is sufficient to assemble it in a class 10,000 environment. Modules on either side can be separately removed for maintenance. The beam exiting each of the system's 48 input sensors is equally divided four ways for injection near the focus of four beams in the transport spatial filter.

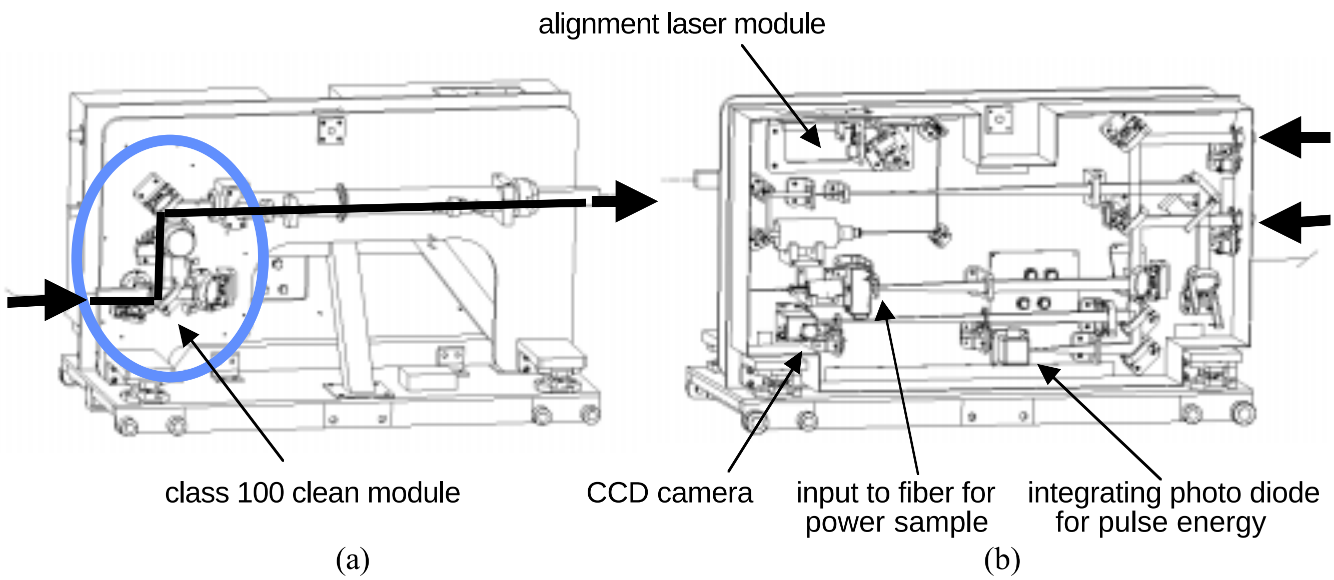

Fig. 4. The input sensor package has two separately removable modules. The one (a) through which the main beam passes is clean to class 100. The other (b) contains all the alignment and diagnostic instrumentation and is clean to class 10,000.

The output sensor packages are also located below the transport spatial filter, and are identified in Figure 1. The beam samples for the output sensors are optically relayed from beam pick-offs within the spatial filter to the output sensors below. Two views of a Pro-E model of an output sensor are shown in Figure 5. Each package comprises two identical sets of components mounted on opposite sides of a central structural plate. This plate and the sides and end pieces of the package form a boxed "I" beam that meets the high stability and stiffness requirements of the alignment system. The components on each side of the mounting plate monitor two beams. On each side, two 1w alignment inputs enter the package on the same path and are temporally multiplexed to the 1w CCD camera, while wavefront and shot inputs from the two beams are spatially multiplexed and enter on parallel but slightly offset paths.

At the bottom of the output sensor package, 1w and 3w beam samples are each injected into fiber optic bundles for transport to the power sensors. However, only one of each pair of beams served by an output sensor can be selected on each shot. A beam block stops the other. The fiber bundles carry power samples from a number of output sensors to a separate power sensor package where the multiple samples are combined on a single fast photo diode, but the lengths of the fiber bundles are chosen so that the samples all arrive at different times. Thus, the time resolved signals can be recorded sequentially on a long record length transient digitizer. This approach to capturing the optical power versus time data greatly reduces the number of high cost digitizers required.

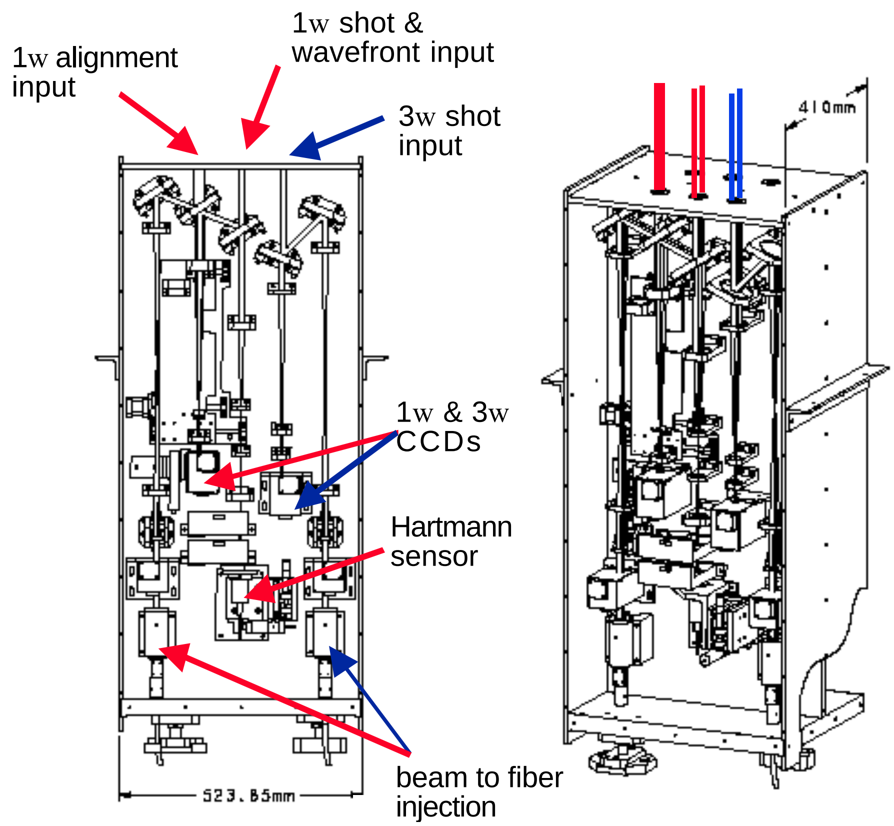

Fig. 5. The output sensor package provides alignment images, near-field shot images, wavefront measurements, and power versus time samples for four beam lines.

3. PROTOTYPE HARDWARE

A prototype of the output sensor package described above has been built and has verified form, fit, and function for the mechanical components. Refinements to assembly procedures and the output sensor test stand design have been made, based on experience gathered with the prototype. Further tests will determine whether the package meets its optical system performance requirements. The package will also provide real hardware for tests of motor control hardware and software.

Fig. 6. Adjustable kinematic mounts support spatial filter towers.

Many of the line replaceable units (LRUs) in the NIF chain must be positioned very accurately and repeatably when they are put into the system. To insure that this requirement is met, kinematic mounts are used in a number of locations to provide a reliable interface between the supporting structure and the base of the LRU. Figure 6 is a photograph of part of a three-axis adjustable kinematic mount prototype. Combining one of these three axis mounts with two similar ones having one and two axes of adjustment provides solid three-point support for each spatial filter tower. The top half of each mount has a matching cone, flat, or groove and is attached to the bottom of the tower. When a prototype tower was repeatedly lowered onto such a set of mounts, the tower position was shown to be reproducible to less than 25mm, well within the 200mm requirement.

In addition to their requirement for accurate positioning during replacement, the spatial filter towers present design challenges with respect to the competing needs of structural stiffness to suppress vibrations and open space for internal components and propagating beams. Figure 7 is a photograph of a prototype spatial filter tower. It has been used to validate computer models of structural properties, explore options for internal mounting of beam control and diagnostics components, and provide test data for tower support and handling.

Fig. 7. A prototype spatial filter tower is used for tests of tower characteristics.

For each of the eight beam lines that pass through a spatial filter tower, a separate internal platform provides a stable mounting surface for spatial filter pinhole positioners, alignment and diagnostic beam pick-offs, far-field alignment references, alignment beam inserters, and main beam injection optics. The components on the platform are designed to be installed, tested, and adjusted in a test stand before the platform is installed in the tower. Some prototype platform components have been built and tested. Figure 8, for example, shows a prototype rotating pinhole positioner and far-field reference light source inserter installed on a platform. Pinhole positioning has been verified repeatable to <10mm, and the positioner has been tested for more than 200,000 cycles without failure, which is equivalent to approximately 10 years of operation. The far-field light source inserter repeats to 1mm. All of these results meet or exceed the design requirements.

Fig. 8. Internal platforms provide precision mounting surfaces for spatial filter tower components.

Prototype precision diagnostic systems for detailed characterization of the laser output one beam at a time have been in use on the technology development laser, Beamlet[5] for several years. They have become very powerful tools and will be moved to NIF early in the equipment installation process.

Computer and other electronic components are essential for operation of the NIF laser alignment and beam diagnostics systems. Prototype hardware and software for driving control motors, gathering video images, processing diagnostic data, and interfacing with the top level integrated computer control system have also been developed and tested. Based on test results, designs have been modified as necessary.

4. CONCLUSION

Title II design is proceeding successfully and is scheduled to be complete in December 1998. Construction and testing of prototype components is an important part of the design activity. The test results so far have been favorable, and additional prototypes will be built and tested to demonstrate performance in as many areas as possible. Procurement of production hardware will begin in FY99.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Steven J. Boege, Erlan S. Bliss, Clifford J. Chocol, Fred R. Holdener, John L. Miller, John S. Toeppen, Charles S. Vann and Richard A. Zacharias, “NIF pointing and centering systems and target alignment using a 351 nm laser source”, Second Annual International Conference on Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series Vol. 3047, pp.248-258, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1996.

2. Fred R. Holdener, Elden Ables, Erlan S. Bliss, Steven J. Boege, Robert D. Boyd, Clifford J. Chocol, Donald T. Davis, Robert D. Demaret, R. Ed English, Curt W. Laumann, John L. Miller and Stanley W. Thomas, “Beam control and diagnostic functions in the NIF transport spatial filter”, Second Annual International Conference on Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series Vol. 3047, pp. 692-699, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1996.

3. Stan Thomas, Bob Boyd, Don T. Davis and Bob Hall, “Temporal multiplexing for economical measurement of power versus time on NIF”, Second Annual International Conference on Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series Vol. 3047, pp. 700-706, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1996.

4. Stanley C. Sommer and Erlan S. Bliss, “Beam Position Error Budget Developed for NIF”, Third Annual International Conference in Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series, this Vol., Society of Photo-Optical Instrumentation Engineers, Monterey, 1998.

5. Scott C. Burkhart, K.R. Brading, P.M. FERU, M.R. Kozlowski, J.E. Murray, J.E. Rothenberg, B.M. Van Wonterghem, P.J. Wegner and T.E. Weiland, “High-fluence and High-Power 1.05mm and 351 nm Performance Experiments on Beamlet”, Third Annual International Conference in Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series, this Vol., Society of Photo-Optical Instrumentation Engineers, Monterey, 1998.

6. Calvin Thompson, Carl Knopp and Derek Decker, "Optics Damage Inspection for the NIF", Third Annual International Conference in Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series, this Vol., Society of Photo-Optical Instrumentation Engineers, Monterey, 1998.

7. Richard A. Zacharias, E. Bliss, M. Feldman, A. Grey, M. Henesian, J. Koch, R. Sacks, T. Salmon, J. Toeppen, L. VanAtta, P. Wegner, W. Williams, S. Winters, C. LaFiandra, Raytheon Optical Systems, Inc., and Don Bruns, ThermoTrex Corporation, "The National Ignition Facility (NIF) Wavefront Control System", Third Annual International Conference in Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series, this Vol., Society of Photo-Optical Instrumentation Engineers, Monterey, 1998.

8. Paul J. VanArsdall, R.C. Bettenhausen, F.W. Holloway, R.A. Saroyan and J.P. Woodruff, "NIF Integrated Computer Control System", Third Annual International Conference in Solid State Lasers for Application to Inertial Confinement Fusion, SPIE proceedings series, this Vol., Society of Photo-Optical Instrumentation Engineers, Monterey, 1998.

7. KEY WORD LIST

Key words used in this paper include: laser, alignment, diagnostics, control, NIF, prototypes and inertial confinement fusion.