LASER CONTROL SYSTEMS

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The laser control systems for the NIF align the laser beam, diagnose the beam, and control the beam's wavefront. Accomplishing these tasks requires approximately 12,000 motors and other actuators, 700 cameras and other detectors, and 192 wavefront sensors and deformable mirrors. Many of the systems perform multiple functions and share components to reduce costs and space requirements. All laser control systems have completed Title I designs and are proceeding with prototyping and detailed design.

Introduction

System control components are located throughout each beamline as illustrated in Figure 1. Each of NIF's numerous laser control systems serves one or more of the following three functions: laser beam alignment, beam diagnostics, or wavefront control. We designed many of the control systems to perform more than one function, in order to meet NIF's cost and space constraints. For instance, the input sensors both align and diagnose the initial laser pulse.

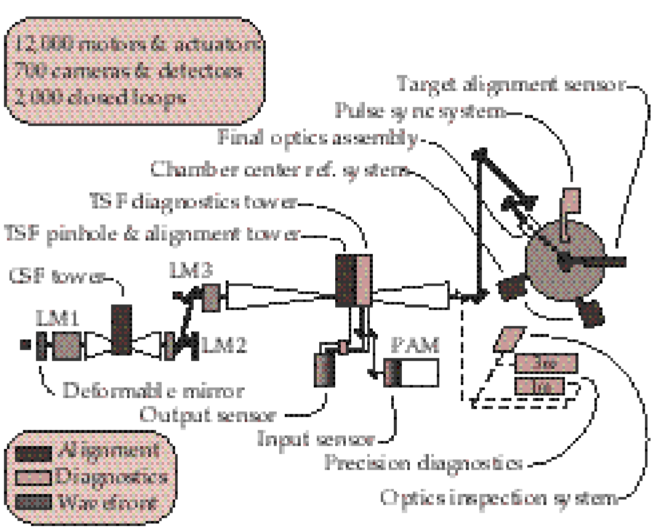


FIGURE 1. Major beam control components for a single NIF beamline. (40-00-1097-2260pb01)

The specific requirements for alignment include positioning the 192 beams within the 40-cm apertures of the laser components, focusing them accurately through the far-field pinholes of the amplifier chain spatial filters, and delivering them to the precise locations specified on the target. All alignment functions are accomplished automatically by recording video images of reference light sources (see "Fiber-Optic Light Sources" on facing page) and beams, calculating what adjustments will achieve the desired relative positions of the imaged objects, and sending the corresponding commands to system motors.

Requirements on the laser diagnostic systems are to measure the beam energy, power versus time, and the near-field transverse profile. The detectors that monitor these parameters are calorimeters, fast photodiodes, streak cameras, and charge-coupled device (CCD) video cameras. Requirements for accuracy and reliability are very high.

Wavefront systems measure optical aberrations on the laser output beams and use a deformable mirror in the four-pass amplifier of each beamline to compensate. The resulting improvement in beam quality leads to higher frequency conversion efficiency and provides better focusing characteristics in the target chamber.

For the sake of clarity, this article is organized by function. Thus, the input sensor components that handle alignment appear in the laser beam alignment section, whereas the input sensor's diagnostic components appear in the beam diagnostics section. Discussion of the front-end processors, which are another important element of laser control, appears in "Integrated Computer Control System" (see p. 198).

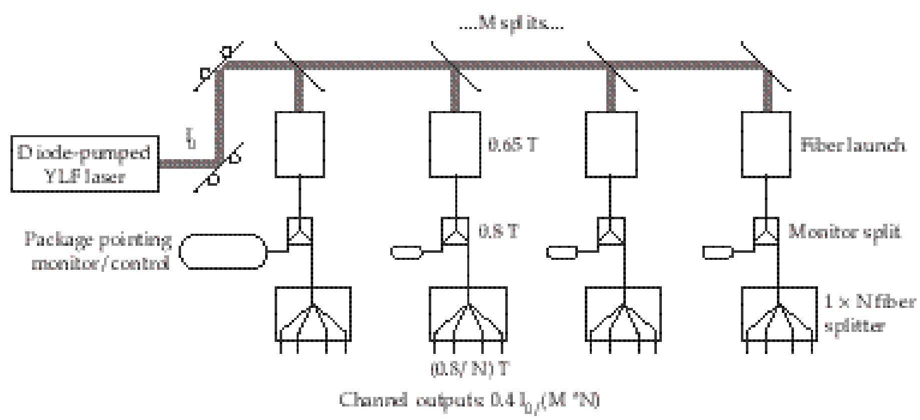
FIBER-OPTIC LIGHT SOURCES

Fiber optics are important to NIF's beam control systems, both in distribution networks that transport light from auxiliary lasers to multiple locations in the beamlines and in fiber bundles that transport light from sampling points in the beamlines to detectors in sensor packages. In the former case, depending on what optics are combined with them, fiber sources can provide full-aperture alignment or optics inspection beams, alignment references for beam centering, or diffraction-limited wavefront reference beams. The table summarizes the location, function, and number of NIF light sources.

Summary by location and function of the light sources required by the NIF Title I design.

Location (see Figure 1)	Function	# Locations	Channels per laser	# of lasers
Input sensor	Alignment, optics inspection, and wavefront control beam	48	16	4
LM1	Reference for beam centering	192	256	2
LM3	Reference for beam centering	192	256	2
TSFalignment tower	Reference for beam pointing and wavefront	192	128	2
TSF diagnostic tower	3ω target alignment optics and inspection beam	192	56	4
Final optics assembly	Reference for beam centering	192	256	2
Total		**1008**		**16**

The figure shows a generic fiber launch platform for NIF alignment light sources. This design derives a large number of channels from a single laser by dividing its power many ways while still meeting the power requirements of particular light source functions. The output power from a laser with a favorable cost per watt value is typically too large to couple directly into an optical fiber. Therefore, the power is first divided several times by small dielectric-coated beam-splitters. Then each beam is focused into the input leg of a fiber-optic splitter that also incorporates a monitoring channel for confirming the proper alignment and power level. The net efficiency of the distribution process is such that about 40% of the laser output is ultimately delivered to light source destinations.



Schematic illustration of a NIF fiber-optic light source distribution platform.
(40-00-1097-2243-pb01)

Title II Activities

In Title II, our priorities are to characterize and choose specific fibers for each light source, based on transmission, power limits, and speckle pattern uniformity and stability. We plan to prototype a 3ω 60-channel fiber-optic fanout, determine power limitations of the splitters, integrate fiber-optic switching requirements into the design, and design and prototype a stable fiber-optic-launch breadboard.

Laser Beam Alignment

In NIF, laser beam alignment is performed in the following areas:

- Input sensor.
- Spatial filter towers.
- Output sensor.
- Target area.

We discuss the design and Title II activities of the alignment components in each of these areas below.

Input Sensor Alignment Functions

The input sensor is located at the output of the preamplifier module (PAM) of the optical pulse generator. For alignment purposes, the input sensor must measure beam pointing and centering, provide alignment references, and provide a beam for alignment through the rest of the system. The sensor must monitor the output at three points within the PAM: the regenerative amplifier, the smoothing by spectral dispersion (SSD) unit, and the multipass amplifier (for the design of these components, see p. 132). The optical design for this alignment system was driven by three factors: (1) resolution and field-of-view requirements, which are directly related to performance of the sensor's function; (2) cost, which limited the number of optical elements and control points; and (3) space, which required that the sensor package fit within the transport optics design footprint. Figure 2 shows isometric views of the multipass and regen sides of the input sensor.

The sensor includes a CCD camera that measures both the near-field and far-field intensity profile of the

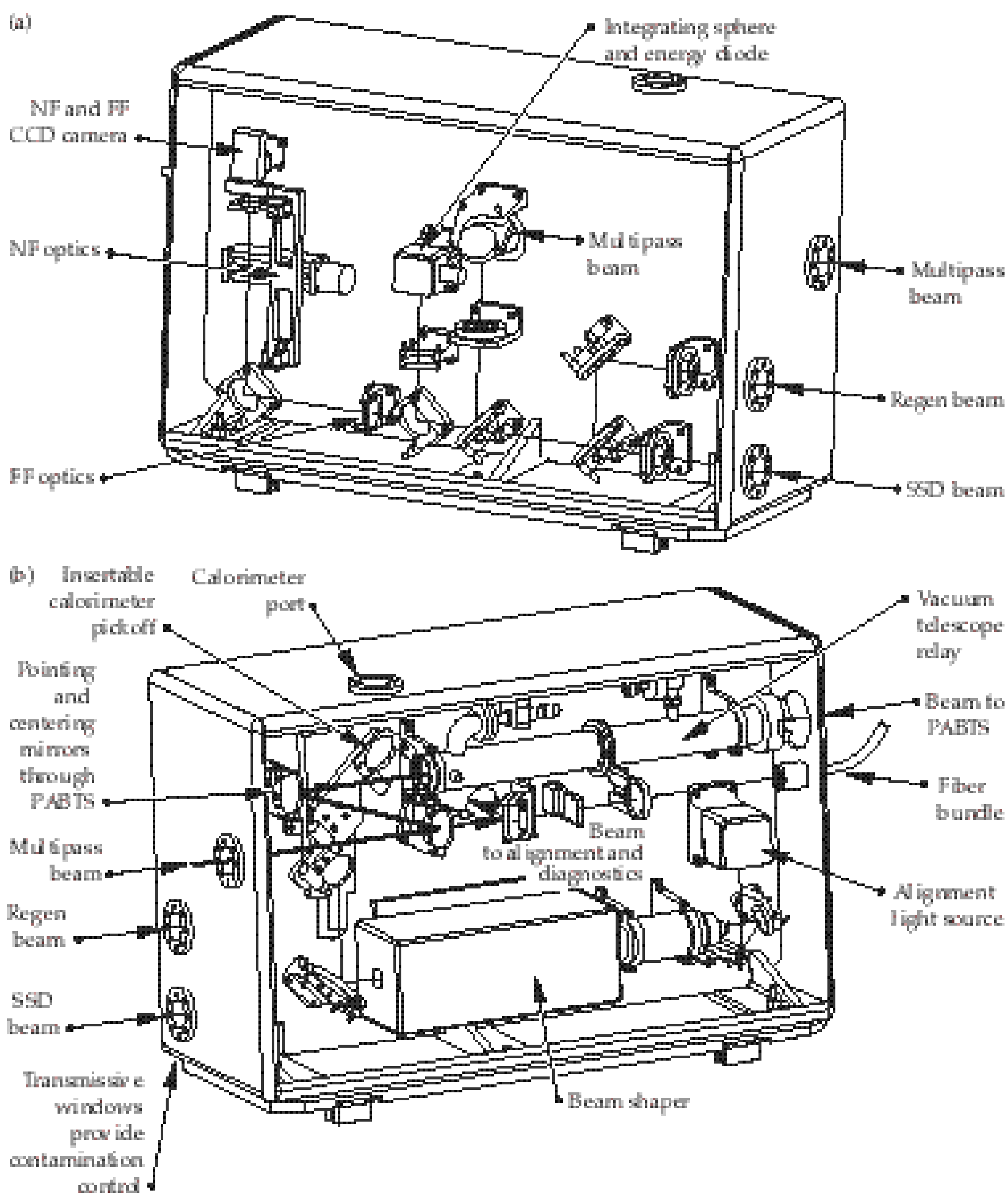


FIGURE 2. Isometric views of the input sensor for the (a) regen side and (b) multipass side. NF and FF mean near field and far field, respectively. (40-00-1097-2244pb01)

beams. For the far field, the camera measures beam pointing and provides a pointing reference for the PAM control points. Figure 3(a) shows the Title I far-field optical design, which meets all of the performance requirements. The same camera is used to produce a near-field image for beam-centering alignment. We had to design this camera to perform its near-field imaging without disrupting the far-field pointing reference. In other words, we had to add insertable lenses to the fixed far-field lens element and camera. Figure 3(b) shows the near-field camera design.

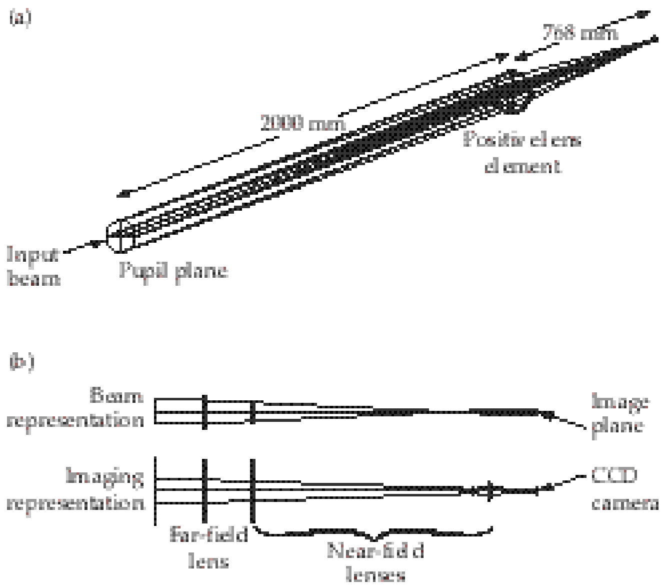


FIGURE 3. (a) The far-field camera design for the input sensor includes a biconvex, 50.8-mm-diam singlet lens. The 6.6-mrad field of view is defined by the active area of the CCD. (b) The near-field camera design uses the far-field optic, as well as three additional spherical biconvex lenses. Inserting and controlling these lenses does not disturb the far-field system. For this function, the field of view is 34 × 34 mm (50% larger than the actual beam), and the object plane is the preamplifier beam shaping aperture (see p. 135). (40-00-1097-2245pb01)

The continuous-wave (cw) alignment light source shown in Figure 2 is used to align the rest of the system. It provides a beam of the same wavelength as the regenerative amplifier (regen) beam. Although the regen beam itself can also be used, it is not always available between shots, and then only at the rate of one pulse per second. The cw alignment beam goes through the input-sensor beam shaper, where it is shaped into a 22.5-mm-square beam.

Title II Activities

In Title II, we will add a fixed centering reference behind the first input-sensor mirror and reoptimize the input-sensor design to match the anticipated evolution of the PAM and the preamplifier beam transport system (p. 136) layout. Finally, we will complete detailed drawings for fabrication.

Spatial Filter Tower Alignment Functions

The spatial filter towers are line-replaceable units (LRUs) that are installed from above at the center of the cavity spatial filter (CSF) and transport spatial filter (TSF) (Figure 4). These towers are complex structures that serve multiple functions, as shown in Figure 5. They provide a stable base for injection optics, diagnostic optics, pinhole assemblies, and beam dumps. Figure 6 shows the general

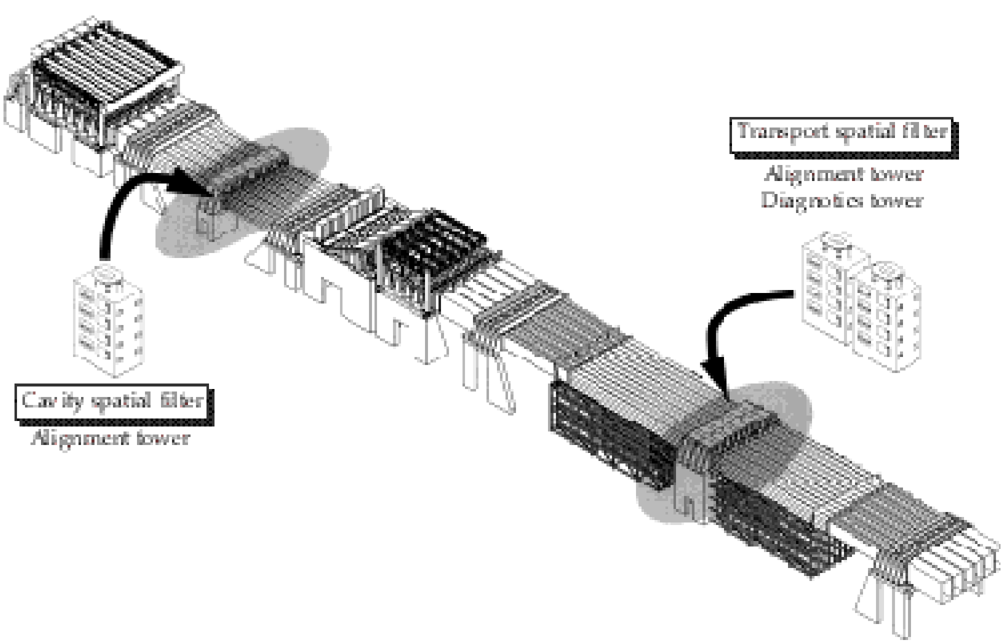


FIGURE 4. Location of the three NIF spatial filter towers. (40-00-1097-2304pb02)

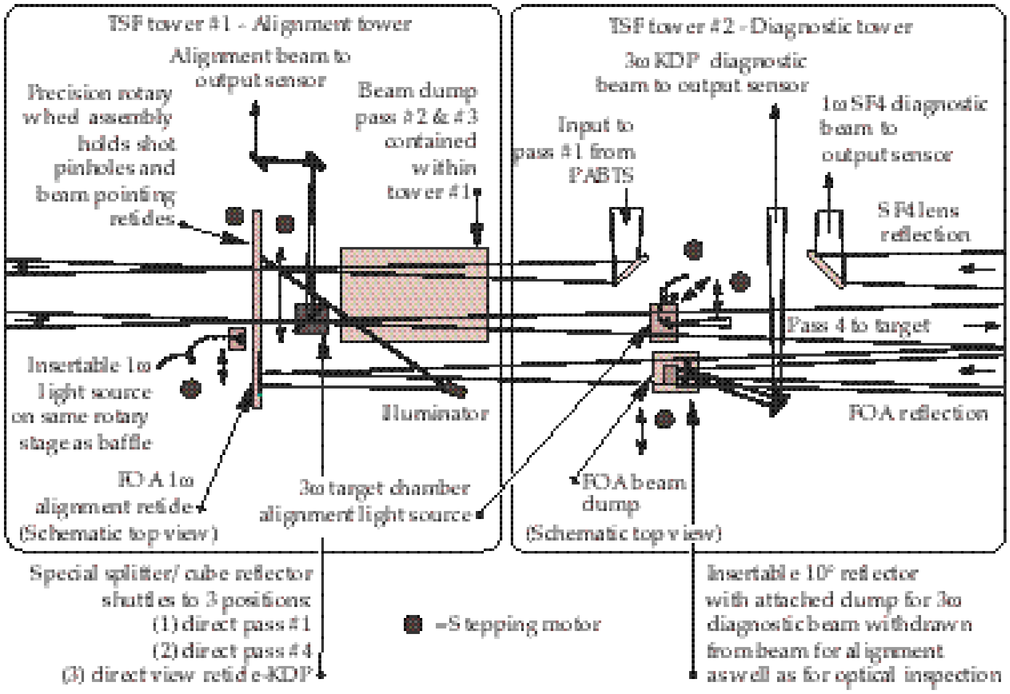


FIGURE 5. A schematic view of the TSF alignment and diagnostic tower components for one beam. The CSF tower performs some of the same functions. (40-00-1097-2247pb01)

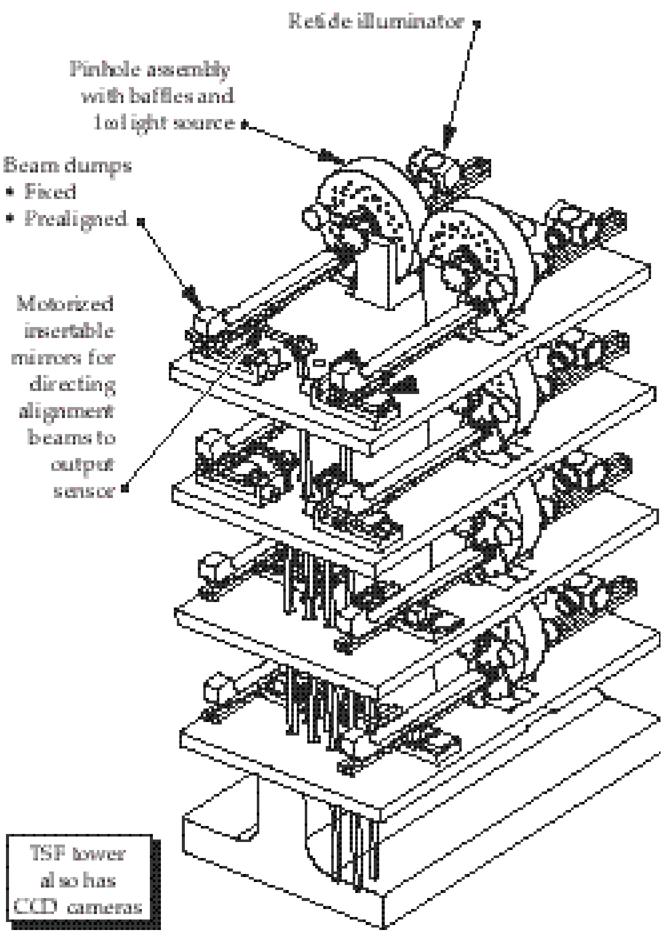


FIGURE 6. The general design of the TSF alignment tower with most of the tower structural elements omitted. (40-00-1097-2248pb01)

design of the TSF tower #1. Each tower has a pinhole assembly—with baffles and a 1ω light source—which positions datums for beam pointing and positions shot-time pinholes. A reticle illuminator backlights reticles to locate pointing references, and pointing images are relayed to the output sensor for the TSF. In the CSF, the reticles are viewed directly by local cameras on the tower. Fixed and prealigned beam dumps absorb energy from faults or leakage from the Pockels cell and from target back-reflections. Alignment optics are removed from the beam path to fire the laser.

The pinhole assembly includes a pinhole wheel with a repeatable reticle inserter, an 80-mm clear aperture, and multiple shot pinholes—10 for the TSF and 30 for the CSF. There are also special pinhole combinations for inspecting optics. A swinging baffle opens for reticle viewing and optics inspection, and closes for shots.

The TSF tower #2 contains some alignment components as well, as shown in Figure 5. It has a 3ω light-source for aligning the laser output to the target and injection optics to establish the correct cone angle for the input beam and to point the beam to pinhole #1. A splitter and absorbing beam dump are removed to align the 1ω reflection from the final optics assembly (FOA) at the pinhole plane. In shot mode, tower #2 directs the reflected beam from the FOA focus lens to the output sensor for diagnostic purposes.

Title II Activities

During Title II, we will evaluate the present tower designs to accommodate the change from 192 to 96 output sensors. We will build and test a prototype tower to verify the structural stability of the tower and its kinematic mounts. We will also finalize the specifications of the components. We plan to prototype critical components—including the pinhole assembly—evaluate alternate beam dump options, and add baffles to the towers as needed to stop stray reflections. Title II will conclude with completion of the detail drawing packages.

Output Sensor Alignment Functions

The output sensor and relay optics packages are located beneath the TSF center vessel, as shown in Figure 7. The sensor and relay optics view the following, for alignment purposes:

- The injection beam at pass 1 for injection pointing.
- Pass 1 in near field for beam centering at the final optics.
- Pass 4 in far field for output pointing.
- Pass 4 in near field for beam centering.
- The reflection from the final optics at the pinhole plane to adjust the angle of the KDP frequency-conversion crystals.

These systems are required to center beams within 0.5% of the beam dimension, center the beams on shot pinholes within 5% of the pinhole diameter, position beams on target within 50 μm rms, and adjust the KDP crystal angle within ±20 μrad over a field of view of ±200 μrad. Light for these tasks is intercepted by a moving beam-splitter cube pickoff near the TSF pinhole plane on the alignment tower (see Figure 5).

Light for all these functions travels to the output sensor along a single path per beam. The pickoffs, relay optics, and transport mirrors are staggered to multiplex the eight beams spatially for each bundle (a bundle is a 4 × 2 array of beams). Two beams per bundle “time share” each output sensor, using beam-splitters and shutters in the transport paths. The nominal beam size in the relays is 20 mm.

Figure 8 shows the output sensor layout and components. Only the 1ω camera is used for alignment. It has two lens systems for near-field and far-field viewing and a motorized focus adjustment. The near-field lens system is shared with diagnostics (see the diagnostics discussion on p. 188), and the far-field lens system performs focused beam and reticle viewing functions. Both cameras have motorized, continuously variable attenuators.

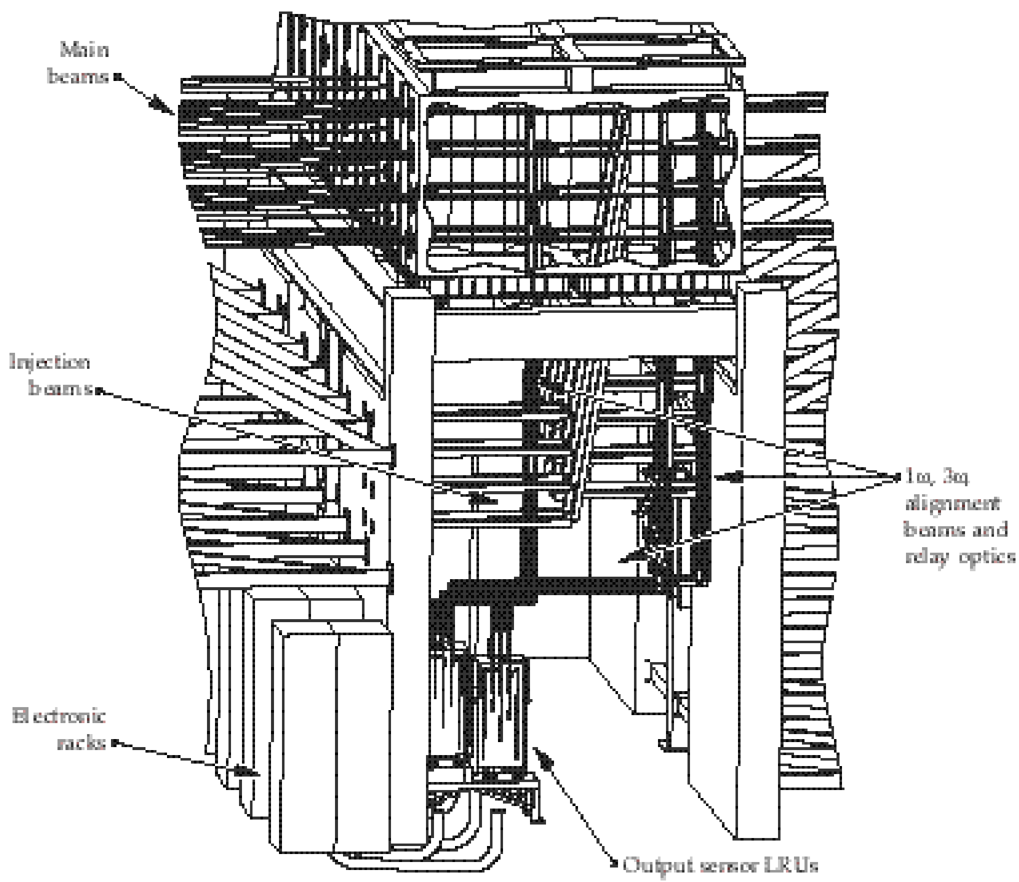


FIGURE 7. The output sensor packages and associated relay optics are located below the center part of the TSF. (40-00-1097-2249pb01)

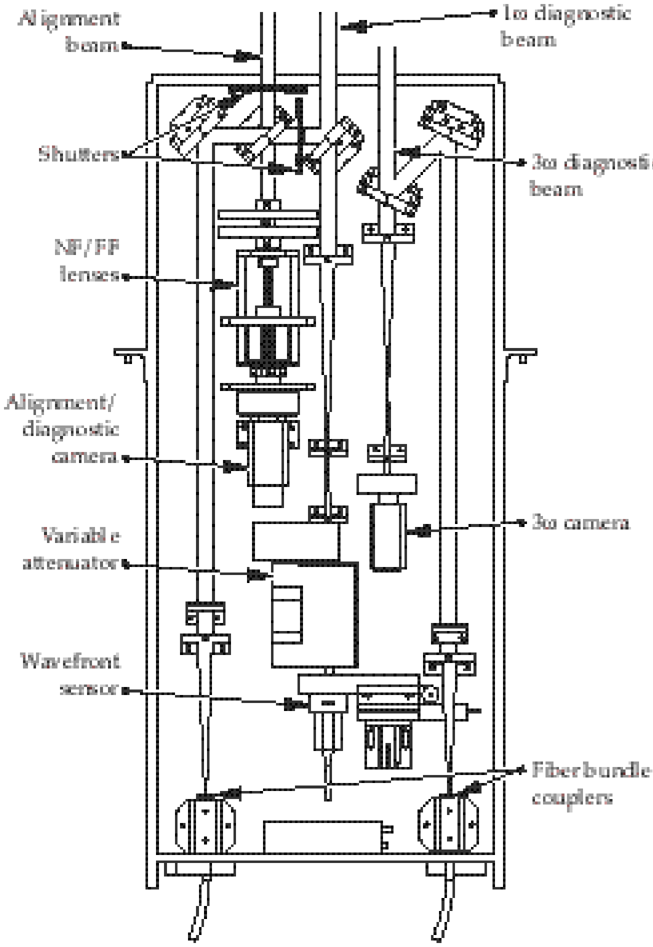


FIGURE 8. Output sensor design, showing components and beams. The output sensor performs both alignment and diagnostic functions. An identical set of components is located on the other side of the same mounting surface. (40-00-1097-2250pb01)

Title II Activities

In Title II we will be evaluating other options for combining the beams at the output sensors and investigating other options for alignment pickoffs. We will also look into simplifying relay configurations by using simple lenses. We will finalize our light level analysis and specify the transmission of the beam splitters and attenuators. Finally, we will examine the designs with an eye to minimizing costs and complete the detail drawing packages.

Target Area Alignment Functions

We have two main alignment systems in the NIF target area: the chamber center reference system (CCRS) and the target alignment sensor. Figure 9 shows the layout of these two systems within the target chamber. The target alignment sensor inserter uses the same positioner design as the target inserters (see p. 172). These inserters, the CCRS modules, and target diagnostics are mounted on the same platform to minimize the relative motion among them. At shot time, the sensor is removed and protective baffles are positioned in front of the CCRS port windows.

The CCRS must provide a stable position reference system in the target bay and be able to position targets repeatably within the narrow field of view (FOV) of the target diagnostics. Its long-term stability must be ≤30 μm, and its FOV must be ±5 cm from the target chamber's center. Figure 10 shows how the CCRS positions target chamber components.

The target alignment sensor positions beams in the target plane and adjusts the final focus lenses to set the spot size. The total deviation for all beams must be ≤50 μm rms, a single beam must deviate no more than 200 μm, and the sensor must achieve a specified central lobe size to ±50 μm. The sensor must operate everywhere within 5 cm of the target chamber center. Figure 11 shows the setup for the target alignment sensor. The sensor has two CCDs, which see both the target and the beams. The assemblies that reflect the beams were designed for minimal deflection and high natural frequency.

Title II Activities

In Title II we will conduct a finite element analysis of the CCRS and target alignment sensor to extend our preliminary mechanical and optical analysis. Prototypes will be built to validate the detailed design.

Beam Diagnostics

NIF's beam diagnostics characterize the beam at key locations in the beamline (Figure 12). These systems are as follows:

- Input sensor.
- Output sensor.
- Calibration calorimeters and final optics diagnostics.
- Temporal diagnostics.
- Optics inspection system.
- Target chamber diagnostics.
- Roving assemblies.
- Trombones.
- Precision diagnostics.

We briefly discuss the requirements, design, and Title II activities of each of these diagnostic systems below.

Input Sensor Diagnostic Functions

The input sensor, in addition to providing certain alignment functions (see p. 182), characterizes the PAM by sampling at the regenerative amplifier, the SSD unit, and the multipass rod amplifier. The sensor measures beam energy, near-field images, and temporal pulse shape. The imaging resolution is 1%

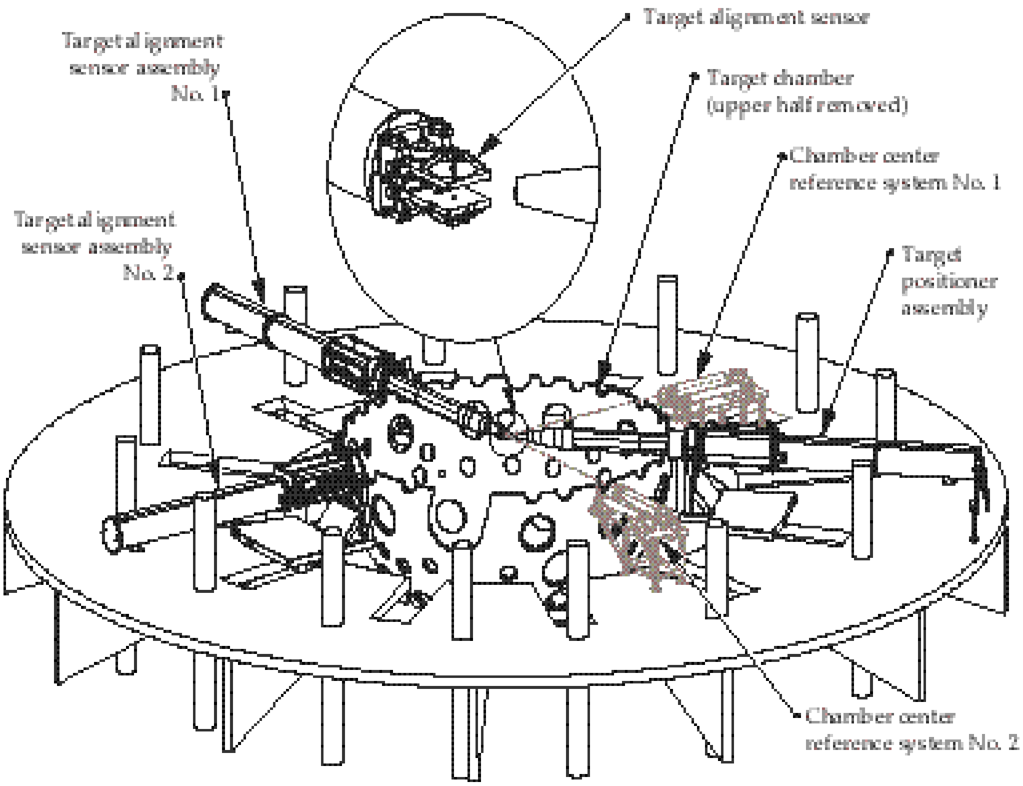


FIGURE 9. Layout of the target area alignment systems. (40-00-1097-2251pb01)

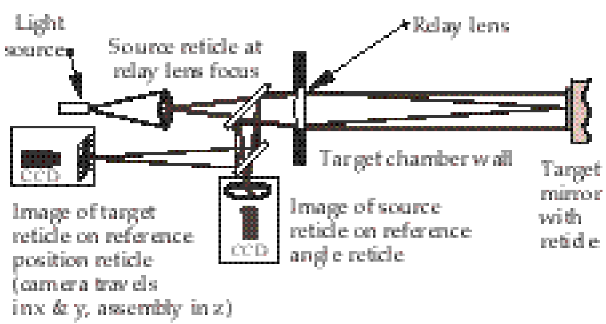


FIGURE 10. The chamber center reference system (CCRS) has two simultaneous modes of operation. It measures a component's target position by imaging its reticle, and measures its orientation by monitoring the direction of light reflected from the reticle. Two CCRS instruments mounted on orthogonal chamber axes precisely locate and orient the target chamber components anywhere within 5 cm of the chamber center. (40-00-1097-2252pb01)

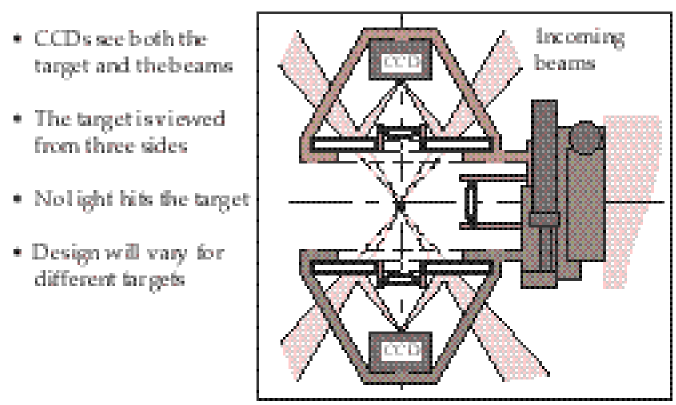


FIGURE 11. The target alignment sensor detects beam positions relative to the target. Two of the three CCDs in the sensor see both the target and the beams, because the images are superimposed. However, no light actually hits the target. (40-00-1097-2253pb01)

of the beam dimension and 2% of the maximum intensity. Figure 2 shows isometric views of the sensor; a schematic of the sensor with its components appears in Figure 13.

Diagnostic samples are obtained from a 1% partial reflector for the regenerative amplifier and through leaky mirrors for the SSD unit and multipass amplifier. The coatings on these mirrors provide adequate signal levels to the energy diagnostics, as well as to the alignment diagnostics.

The energy from the regen, SSD module, or four-pass amplifier is measured with an integrating sphere and photodiode followed by a charge integrator and digitizer. Shutters select which sample is measured and a CCD camera obtains near-field images for each beam prior to or during a shot. An optical fiber bundle sends a sample of the multipass output to the power sensor (see p. 190), where it is time multiplexed with other signals. The PAM output beam can also be diverted to a calorimeter to periodically calibrate the multipass energy diagnostic.

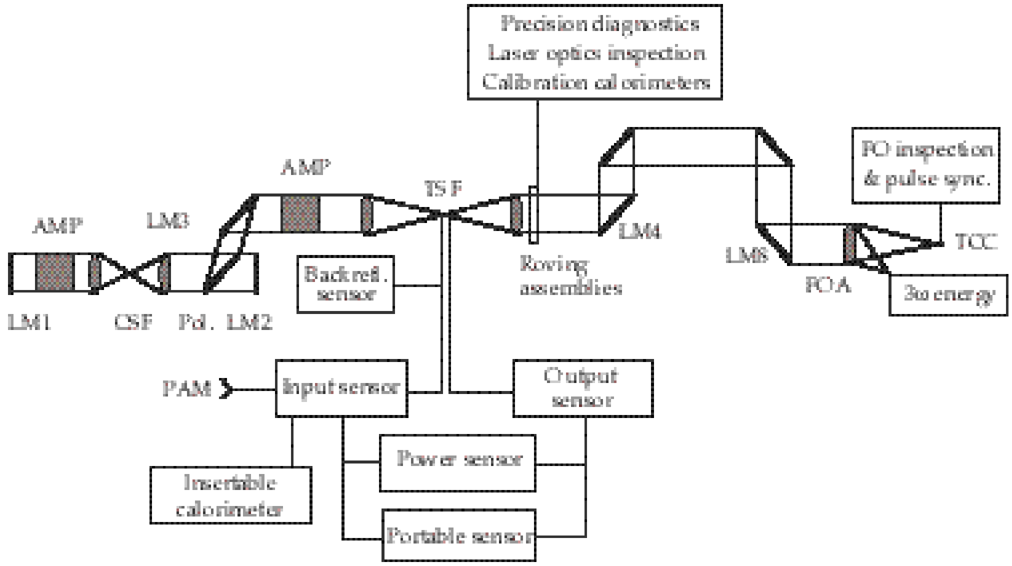


FIGURE 12. Location of the laser diagnostics for NIF. (40-00-1097-2254pb01)

Title II Activities

We have a Title I optical design that meets performance requirements. During Title II, we plan to optimize the coating design, balancing the sampling stability requirements against the desire for high beam-transport throughput. We will also complete the detailed specifications and modeling of the fiber-optic bundle coupling that transmits the multipass output sample. A prototype package will be built from completed detail drawings.

Output Sensor Diagnostic Functions

The output sensor performs many diagnostic tasks in addition to its alignment functions (for alignment discussion, see p. 185). The sensor characterizes the 1ω output (energy, near-field fluence profile, temporal pulse shape, and wavefront) and 3ω output (near-field fluence profile and temporal pulse shape). The 1ω output energy must be measured within 3%, and the 1ω and 3ω temporal pulse shapes must be measured within 2%. The 1ω beam wavefront must be measured within 0.1 waves, and the 3ω output beam must be imaged at the plane of the conversion crystal with a spatial resolution of 2.7 mm. Figure 8 shows the output sensor's general design, and Figure 14 shows a schematic for the output sensor's diagnostic functions.

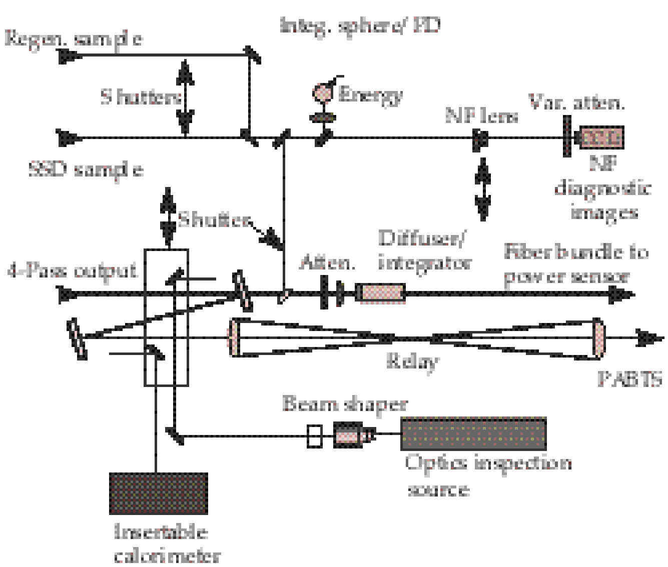


FIGURE 13. Input sensor schematic for beam diagnostics. NF means near field. (40-00-1097-2255pb01)

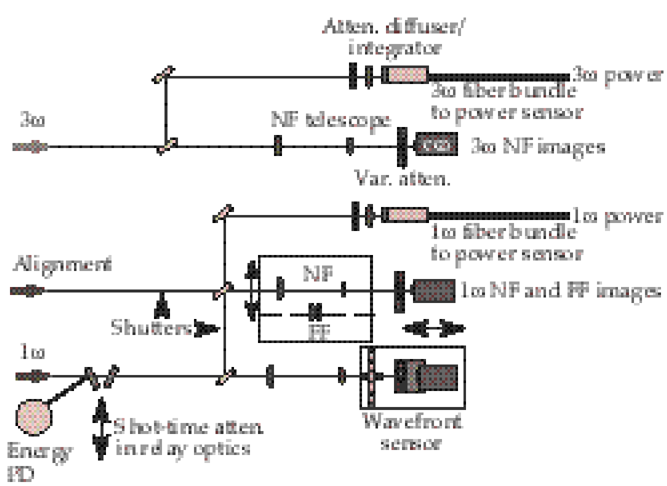


FIGURE 14. Output sensor schematic for beam diagnostics. NF and FF mean near field and far field, respectively. (40-00-1097-2256pb01)

Reflections from existing optics supply samples of the 1ω and 3ω beams. The 1ω sample reflects from the flat exit surface of the transport spatial filter output lens. This surface is coated with a solgel antireflection coating, (nominally 0.1% R). The lens is tilted by 0.8 mrad to offset the reflected sample from the pass #4 path. The 3ω sample reflects from the flat entrance surface of the target chamber lens in the final optics assembly. This lens is also tilted by 0.6 mrad to offset the reflected sample beam from TSF pass #4 path, and its coating is similar to that on the SF4 lens sampling surface. Because the 3ω sample beam propagates at a small angle relative to the TSF output beam, it becomes decentered. The clear apertures of SF4, LM4, and LM5 must be increased to clear both pass #4 and the 3ω beam. Pickoffs for the beam samples are near the focus in the TSF. Pickoff optics for 1ω and 3ω sample beams are located on TSF tower #2, as shown in Figure 5. Relay optics transport the beams from the TSF to the output sensors beneath the TSF center vessel. For preshot wavefront control, two diagnostic beams per bundle "time share" each output sensor, using beam splitters in the transport paths. One beam from each pair of beams is diagnosed for each shot. The 1ω energies are measured on all beams for each shot.

The output sensor has three CCD cameras, each with continuously variable attenuators. One camera—shared with the alignment functions—images the 1ω near-field profile, the second images the 3ω near-field profile, and the third is the detector array for a Hartmann wavefront sensor (see p. 194 for a discussion of the Hartmann sensor). The 1ω energy is measured by an integrating sphere with a time-integrated photodiode, which is inserted at shot time. Power samples are sent to the power sensor (see p. 190) using two optical fiber bundles.

Title II Activities

For the output sensor diagnostic systems, our Title II priorities include evaluating other options for combining beams at the output sensor, optimizing the fiber coupler for maximum transmission, possibly simplifying relay configurations, completing specifications for the SF4 sampling surface, finalizing our light level analysis, and specifying transmission of the beam splitters and attenuators. We will also analyze the stray light, and specify baffles, stops, and wavelength selective filters. An initial set of drawings will be used to build a prototype.

Calibration Calorimeters and Final Optics Diagnostic Functions

Calorimeters, which measure beam energy, are used in three areas of NIF: the input sensor, the output sensor, and the final optics diagnostics. Each input sensor has a port for manual mounting of a 5-cm calorimeter to calibrate the sensor's energy diode without opening the beamline [Figure 2(b)]. The output energy diodes are calibrated using two groups of eight roving bundles of 50-cm calorimeters—one for each laser bay. Each group can be remotely positioned to intercept the outputs from one eight-beam bundle at a time. Finally, 192 10-cm calorimeters in the final optics diagnostics measure a fraction of each beam's 3ω energy as it propagates toward the target.

We use calorimeters similar to those on Nova. The 5-cm calorimeters are an off-the-shelf design, and the 50-cm and 10-cm calorimeters are scaled versions of the 40-cm ones used in the Nova target chamber. These calorimeters can meet the NIF requirements.

The final optics diagnostics uses a diffractive splitter to obtain a sample for the 3ω calorimeter (Figure 15). This calorimeter calibrates the 3ω power for each shot. It must operate in a vacuum, and have a damage threshold >3 J/cm^2 at 351 nm, a 10 × 10 cm aperture, a 1–60 J energy range, a repeatability of <1% at the 30 J level, and a linearity of <1% over a range of 50:1. The sampling grating on the flat surface of the focus lens will have a solgel antireflective coating, a transmission of >98% for the zeroth order of 3ω, and a 40 × 40 cm aperture. It must also focus the sampled beam in 1.5 m. The diffractive splitter design will be demonstrated on the final optics test assembly on Beamlet; however, we have evaluated the calorimeter/diffractive splitter system as a whole and know it can meet NIF's system requirements.

Title II Activities

After testing aspects of the 3ω final optics diagnostic design on Beamlet, we will produce the final design drawings to complete Title II.

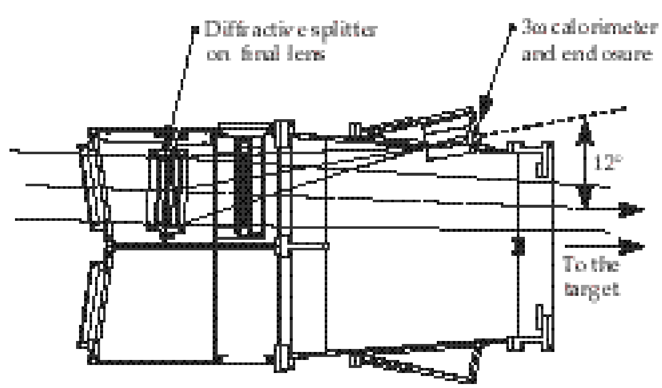


FIGURE 15. The final optics diagnostics uses a diffractive splitter and volume-absorbing calorimeter. (40-00-1097-2257pb01)

Temporal Beam Diagnostics

Temporal diagnostics includes two portable sensors, rack-mounted power sensors near the input and output sensors, and a back-reflection sensor. NIF will have two portable streak cameras, mounted on carts, that can each be used in place of a normal power sensor for one beam at a time. The streak cameras must have a time resolution of 10 ps, a dynamic range of 1000:1, and multiple channels, and must be easily movable among the other sensor packages. Each camera can handle 19 sample inputs—1ω or 3ω—through fiber-optic bundles. One of four sweep times can be selected—1.5 ns, 5 ns, 15 ns or 50 ns—with resolutions from 10 ps (for 1.5 ns) to 250 ps (for 50 ns).

Each power sensor must have a dynamic range of 5000:1, a record length of 22 ns, an accuracy of 2% over a 2-ns interval, and a rise time of 250 ps. It takes samples on fiber bundles from the output and input sensors, and time multiplexes 12 signals to minimize costs. Figure 16 shows a schematic of the Title I design. The transient digitizer in the sensor is a commercial technology with a long record length. One photodiode detects signals from four input sensors and eight output sensors—a total of eight 1ω signals and four 3ω signals. Time separation is achieved using the propagation time through the laser and optical fiber delay lines for signals close in time. The dynamic range of the eight-bit digitizer is extended using four channels, each with a different sensitivity. The 12 signals are multiplexed into the long-record digitizer.

Title II Activities

During Title II, we will analyze both optical and electronic reflections to ensure there is no interference with the data. We will also evaluate the availability, transmission, and cost of the fiber used for the 3ω signals. The diagnostic fiber system must transmit enough light to the photodiode for measurement and provide correct timing for beam diagnostics sharing.

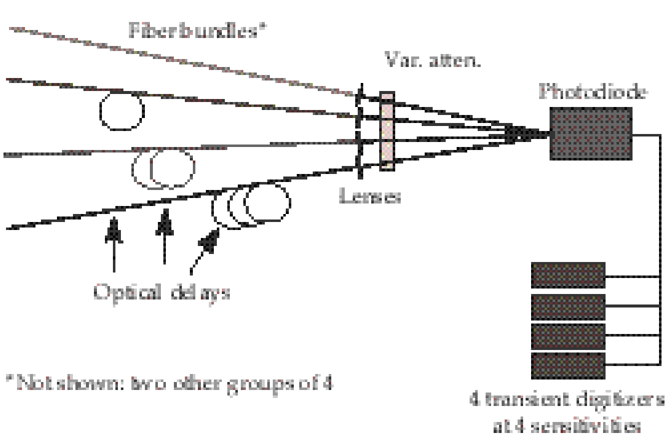


FIGURE 16. Schematic diagram of a power sensor in which time-multiplexed optical pulses are combined on a common photodiode, and the electrical outputs drive multiple channels in transient digitizers. (40-00-1097-2258pb01)

On-Line Optics Inspection

One on-line optics inspection system is located in each switchyard, and one more at target chamber center. These systems have access to each beamline through a set of translatable mirrors described later (p. 192). The requirement for main-beam optics is to detect flaws ≥5 mm, which is 1/4 of the critical flaw size. Our goal is that these systems detect defects ≥0.5 mm. We considered a number of issues when designing these systems. First, we selected dark-field imaging since damage spots appear best against a dark background. This allows us to detect spots below the resolution limit. Our imaging scheme is to backlight the large optics with apodized and collimated laser illumination sources. Undisturbed light is intercepted by a stop in the dark-field optics, but light diffracted from damage spots is imaged onto a CCD camera. Second, the systems' resolution will be limited by one of two factors: the far-field aperture in the TSF or the number of pixels in the cameras' CCD arrays. We must properly account for these limitations in the design. Third, depth of field will be short enough to isolate all but the most closely spaced optics. Fourth, use of different pinhole combinations in the CSF and careful image processing can "strip away" any overlaid images.

The laser bay optics are inspected with the high-resolution cameras located in each switchyard. Figure 17

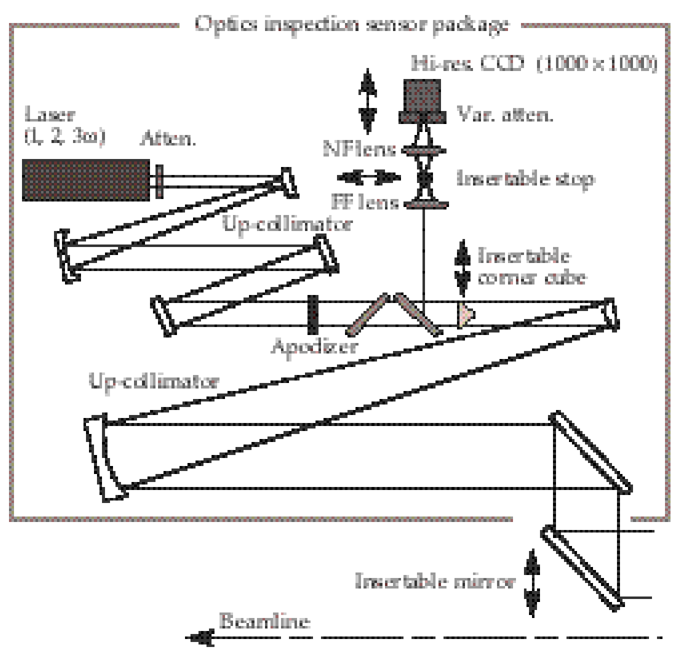


FIGURE 17. Inspection scheme for all but the final optics. One such inspection system resides in each switchyard. NF and FF mean near field and far field, respectively. (40-00-1097-2259pb01)

shows the layout of a switchyard inspection package. For optics LM1 through SF4 in the main laser cavity, the illumination source is the alignment laser located in the input sensor. This alignment beam is injected into the TSF along pass 1, and LM1 is aligned to return the beam along pass 4. The inspection package captures dark-field images at each plane containing an optic. Image subtraction software will help detect the changes from previous inspections.

For inspecting LM4 through the first surface of the final focus lens, the switchyards' 1ω source will be injected toward the target using the outward-looking roving mirror (p. 192). The first surface of the final focus lens will be aligned to retroreflect a portion of this beam. Dark-field images will be captured by the inspection system in the switchyard at each plane containing an optic.

For inspecting the final optics, we will image through the kinoform phase plate (KPP) at 3ω using a damage inspection package inserted at the target chamber center (described further in the next section). This viewer will have a sufficiently short depth of field to discriminate between the closely spaced final optics elements.

Title II Activities

Our priorities during Title II include obtaining dark-field images from Beamlet using the NIF on-line inspection approach, and modeling and validating the preliminary optics designs for the switchyard and target chamber optics inspection systems. We will also design a reflective-optics up-collimator for the switchyard inspection packages and start evaluating image processing strategies.

Target Chamber Beam Diagnostics

Target chamber diagnostics include the pulse synchronization detector module and the target optics inspection system. Both are located at the center of the target chamber at the end of the diagnostic instrument manipulator, as shown in Figure 18(a). Similar adjustments are required for both the pulse synchronization and final optics inspection modules. They can be oriented to any beam position, including direct drive. Translation commands for the diagnostic manipulator and angle commands for the modules come from the CCRS (p. 186). The maximum move time to intercept light from a different four-beam quad is 5 s; the typical time is <0.8 s.

Figure 18(b) shows the components of the synchronization module. The pulse arrival times at target chamber center must be set with 30-ps relative accuracy. The module must simultaneously capture signals from the four beams of a final optics assembly quad and position each focused beam on the end of a separate fiber bundle with an accuracy of <100 μm. The fiber bundles carry the optical signals to a streak camera where their relative times of arrival are compared. The signal is obtained by firing a rod shot and capturing the leakage of 1ω radiation through the conversion crystals.

The final optics damage inspection module, also located at target chamber center, is shown in Figure 18(c). The module examines the closely spaced final optics that are not observable by other means. The final optics are backlit with collimated 3ω radiation. A high-pass filter,

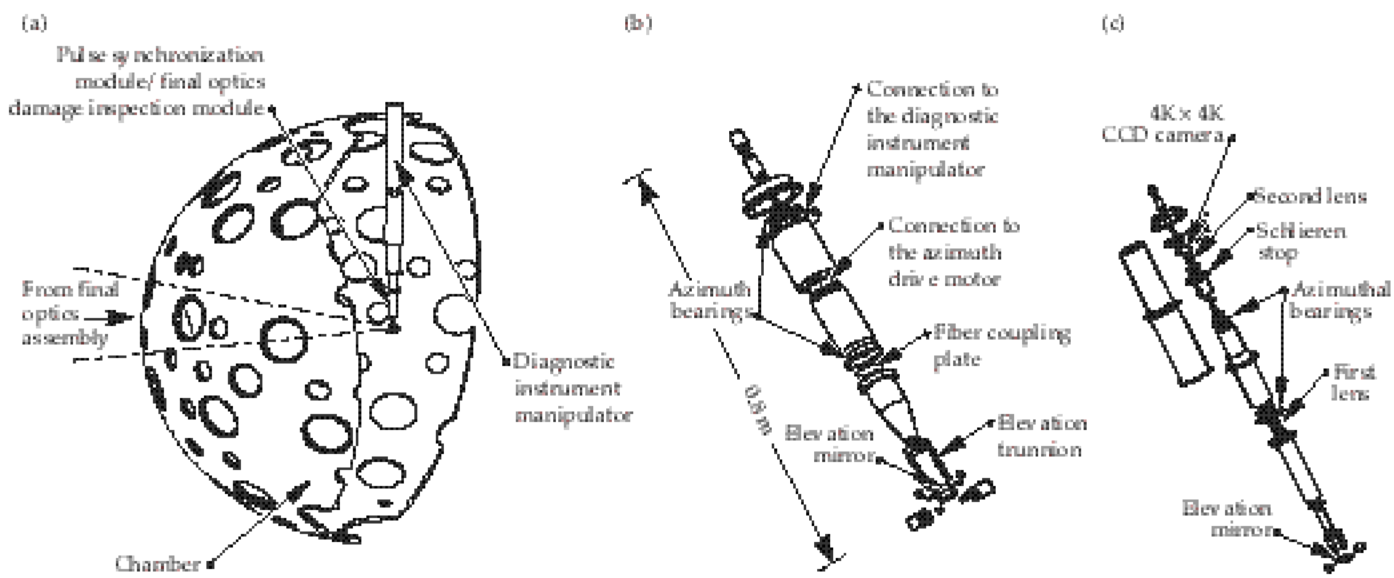


FIGURE 18. (a) The pulse synchronization detector module and final optics damage inspection module can be attached to the end of the diagnostic instrument manipulator and inserted into the center of the target chamber. (b) An exploded view of the pulse synchronization module. (c) An exploded view of the final optics damage inspection module. (40-00-1097-2261pb01)

with a central schlieren stop placed at the focus, removes those rays that are not deviated by flaws. A CCD camera captures data from the full-aperture image. The camera, lenses, schlieren stop, and filters rotate as a unit in the azimuthal direction.

Title II Activities

Our Title II engineering priorities for these systems are to determine the mechanical and electrical interface of both modules with the manipulator, and implement a design for the rapid installation and removal of the modules from the manipulator. We will also complete the detailed design for many of the components and interfaces of the two systems.

Supplemental Beam Diagnostics

As described above, the NIF design includes significant diagnostic capabilities on each beamline. However, it will be important to be able to calibrate some of these measurements, to verify that they are operating correctly, or to collect more detailed information. For this purpose, additional diagnostics that can be used on one or a few beams at a time are located in each switchyard. They include full-aperture calibration calorimeters and a suite of precision diagnostics.

Figure 19 shows the layout of components related to supplemental diagnostics in one of the switchyards. An array of eight calorimeters, the "roving calorimeter assembly," travels on horizontal rails to any of the 12 bundle locations. If desired, each of the eight calorimeters can collect the output from the corresponding beam in that bundle. However, any of the eight calorimeters can also be rotated toward the laser on its outside vertical edge so that it allows the beam to pass. Beams that are allowed to pass continue on to the target chamber or are directed to the precision diagnostics as described below.

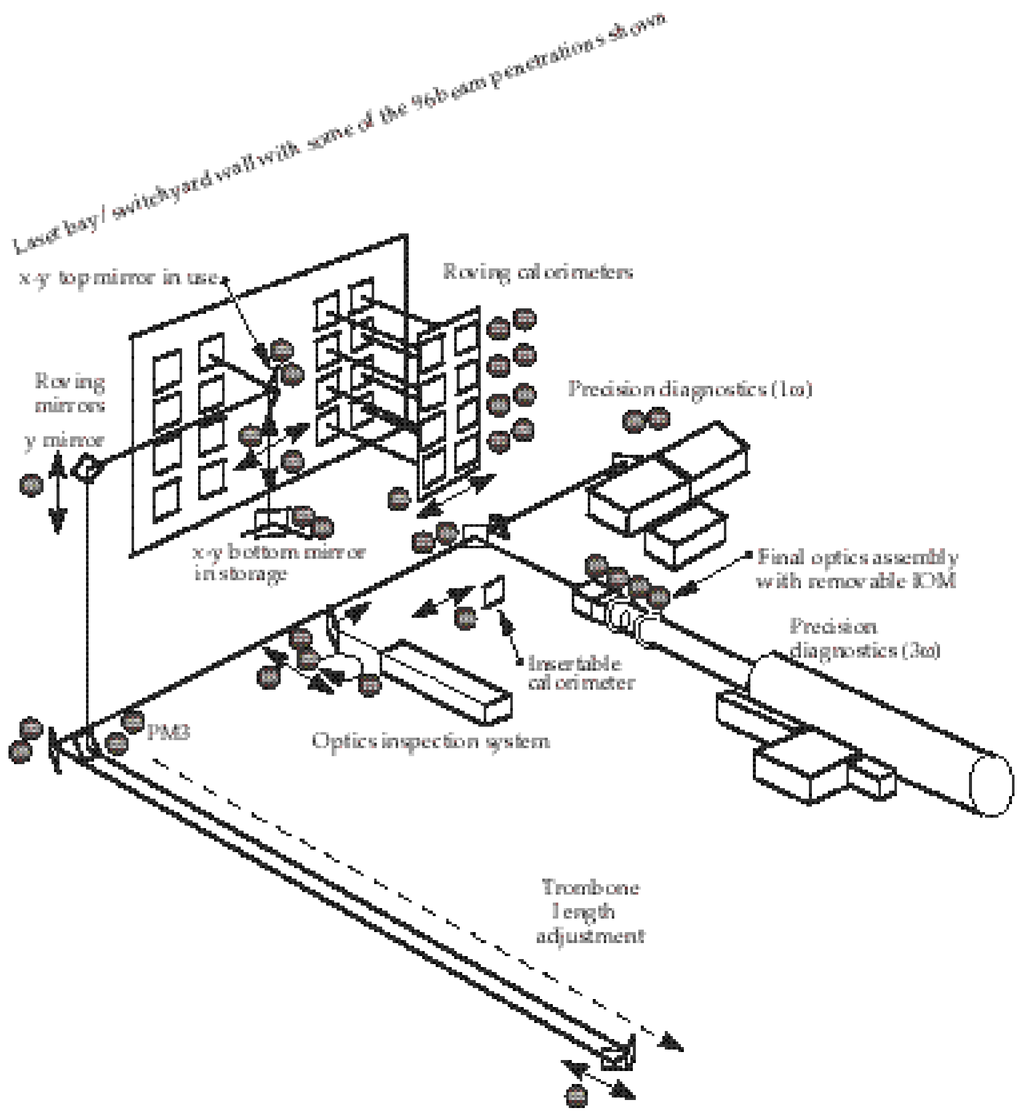


FIGURE 19. Supplemental diagnostics for calibration and for a variety of detailed measurements are located in the switchyard. (40-00-0398-0381pb01)

The optical-mechanical system designed to intercept any one beam in each switchyard and send it toward the precision diagnostics is called the “roving mirror system.” It comprises an additional pair of parallel horizontal rails, two pairs of parallel vertical rails, and three translatable mirrors. The x-y top mirror [Figure 20(a)] in combination with the y mirror picks off a beam and diverts it toward the precision diagnostics and optics inspection package (see p. 190 and Figure 17). The x-y bottom mirror, combined with the y mirror, provides a path from the optics inspection package to the target chamber [Figure 20(b)].

Each of the roving calorimeter and x-y mirror assemblies weighs about 1000 lb. The assemblies are belt-driven by motors fixed at the target bay end of the enclosure. The drive packages include stepper motors, incremental encoders, and fail-safe breaks. The time to move from one beam to an adjacent beam is estimated at 16 s. All of the components reside within an enclosure that maintains a sealed argon gas environment, and the mechanisms must be designed to avoid production of particles that might contaminate the nearby optics.

The precision diagnostic stations are shared diagnostics that measure laser output performance one beam at a time using more extensive instrumentation than that found in the output sensors (see Table 1). During installation and activation, the precision diagnostics will be used to verify the performance of each beam, including its dedicated diagnostic packages. The 3ω precision diagnostics, illustrated in Figure 21, will measure frequency conversion characteristics of the selected beam using a separately selected integrated optics module (IOM). Each IOM comprises the set of optics, including frequency conversion crystals and final focus lens, that is normally mounted at each beam’s entrance to the target chamber. The precision diagnostics provide the only capability for simultaneously measuring high-power 3ω beam properties at the full 40-cm near-field aperture and in a far-field plane equivalent to the target chamber focus. Once NIF is operational, the station will be available for diagnosing beamline and component problems and for performing laser science experiments.

The precision diagnostic station will be able to measure the following aspects of the 3ω laser pulse:

- Energy, with an accuracy of 3%.
- Power vs time, with a dynamic range of ≥50:1, an accuracy of 4%, a rise time of 250 ps, and a record length of 22 ns.
- Focused spot size and smoothness, with 30-μm spatial resolution and 10-ps temporal resolution for a selected 1.5-ns period.
- Near-field spatial profile in the frequency conversion crystal plane, with 2.7-mm resolution.
- Prepulse energy, at levels $\leq 0.25 \times 10^8$ W/cm^2 in equivalent target plane.

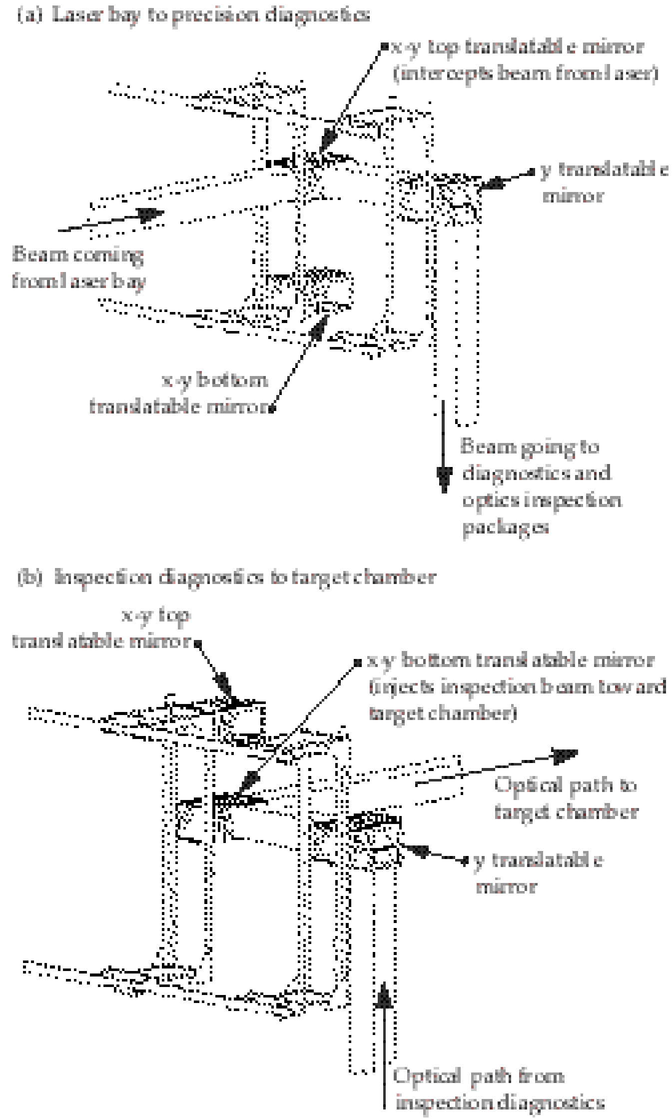


FIGURE 20. Two roving mirror system configurations provide (a) a path from the laser bay to the precision diagnostics station and (b) a path from inspection diagnostics to the target chamber. (40-00-1097-2262pb01)

Title II Activities

As we complete the design, we will specify transport mirror sizes and coatings, design a modified final optics assembly 3ω calorimeter spool, choose an effective method for mounting the IOM, and develop procedures for independent alignment of the supplemental diagnostics modules. We must also analyze thermal and vibration characteristics to verify that they meet the same stability requirements as the corresponding main beamline components.

Wavefront Control

During preparations for a pulsed shot, the wavefront control system monitors the wavefront of each alignment laser at the beamline output and automatically

TABLE 1. The 1ω measurement capabilities of the precision diagnostic station compared to those of the output.

Measurement	Precision diagnostic	Output sensor
Energy		
Range	To 20 kJ	To 20 kJ
Accuracy	Better than 1.5%	3%
Power resolution	<40 ps or 100 ps	250 ps
Far-field imaging FOV	±180 μr (best)	None
Near-field imaging resolution (in main beam)	~1.4 mm and / or ~300 μm	1.6 mm
Wavefront		
Hartmann precision	Better than λ / 20	λ / 10
Radial shearing interferometer precision	~0.1 λ (16× reference)	None
Schlieren		
Energy balance	Better than 15%	None
Power resolution	~10 ps and / or 100 ps	None
Far-field imaging FOV	±800 μr	None
Near-field imaging resolution	~1.6 mm (in main beam)	None
Prepulse sensitivity (3ω equiv.)	Better than 0.25×10^8 W / cm^2	None
Flexibility	Versatile	Fixed

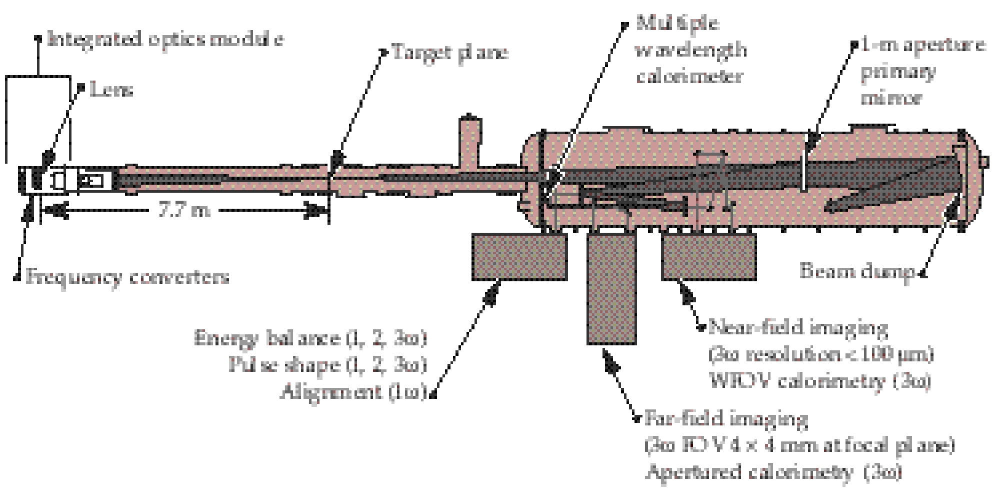


FIGURE 21. The precision diagnostics measure the characteristics of a full-power NIF beamline. The larger vacuum chamber is necessary to avoid high-intensity air breakdown and to expand the beam enough that it doesn't damage beam-splitting optics.
(70-00-0796-1536pb01)

compensates for measured aberrations using a full-aperture deformable mirror. In the last few minutes before a shot, the controlled wavefront is biased to include a precorrection for the estimated dynamic aberrations caused by firing the flashlamp-pumped amplifiers. One second before a shot, closed-loop operation is interrupted, and the Hartmann wavefront sensor is configured to measure the pulsed wavefront. The measured pulsed wavefront error provides additional information for setting precorrection wavefronts prior to the next shot.

Requirements for the system include operation at 1 Hz closed-loop bandwidth and reduction of low spatial frequency angles in the beam to less than 20 μrad. The range of the system measured at beamline output must be at least 15 waves for simple curvature (second-order correction) and 4 waves of fourth-order correction on both horizontal and vertical axes. Figure 22 shows the location of system components. The three main components are the Hartmann wavefront sensor, the deformable mirror, and the computer controller.

Hartmann Sensor

The Hartmann sensor, illustrated schematically in the Figure 23 inset, includes a 2-D array of lenslets and a CCD video camera. The output sensor (Figure 24)

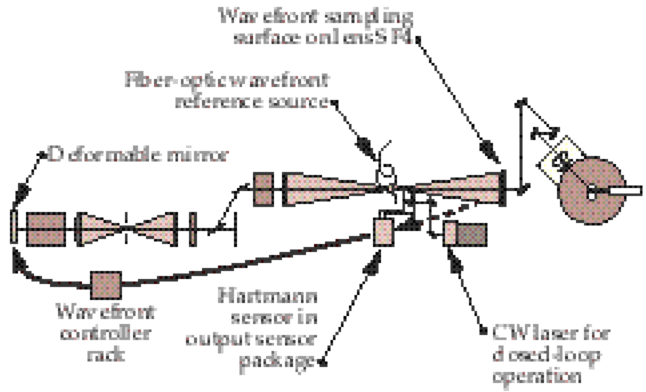


FIGURE 22. General location of the primary wavefront control components—the Hartmann sensor, the deformable mirror, and the wavefront controller. Lens SF4 provides a wavefront sampling surface. (40-00-1097-2265pb01)

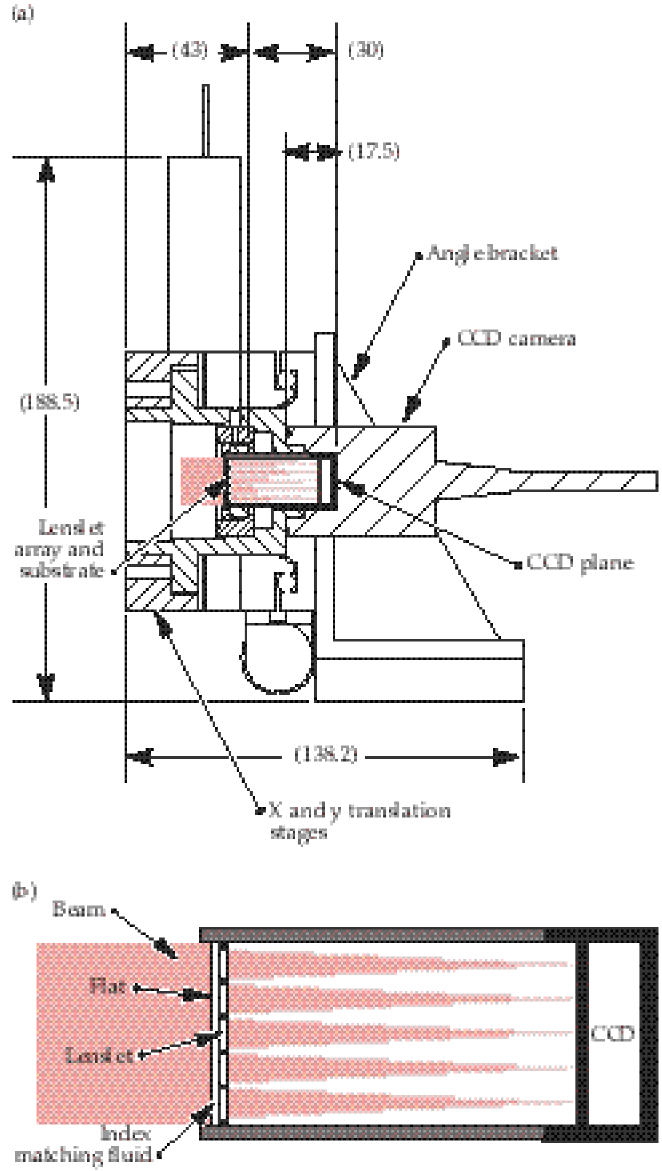


FIGURE 23. (a) A sectional view of the Hartmann sensor. (b) The Hartmann sensor works as an array of pointing sensors with a shared CCD detector. (40-00-1097-2266pb01)

delivers a demagnified image of the output beam to the lenslet array. Each lenslet collects light from a specific part of the beam and focuses it on the CCD. The focal length must correspond accurately to the distance from the lenslet to the CCD, and this result is obtained using an index-matching fluid sealed between the lenslets and an optical flat. The lateral position of the focused spot are a direct measure of the direction of the light entering the lenslet. Directional data from the 77 hexagonally packed lenslets of the NIF sensor are processed to determine the output wavefront with an accuracy of ≤0.1 wave and a spatial resolution of 4.5 cm in the 40-cm beamline aperture.

Title I hardware specifications for the Hartmann sensor include a frame-capture video camera with 1.3-cm format, a pixel array of at least 512 × 480, and a dynamic range of 200:1. The camera should operate on 0.75 μW of continuous 1-μm light or a pulse energy of 12 nJ and be available in a remote-head configuration to minimize heat generation within the output sensor package. Higher input signals will be reduced with high-optical-quality variable attenuators. To minimize stray light, the lenslet array assembly will be antireflection-coated on both sides, and all parts of the input aperture falling between lenslets will be blocked with an opaque mask.

Title II Activities

During Title II, we will optimize the variable attenuator design, qualify a vendor for the lenslet arrays, and evaluate options for using the sensor on two beams at shot time. We also plan to build a prototype unit.

Deformable Mirror

The NIF design includes 192 large-aperture deformable mirrors for wavefront control in the main laser cavity. The required optical clear aperture is approximately 400 × 400 mm square. The mirror shape will be determined by the displacements of 39 replaceable actuators spaced 80 mm apart. The actuators have numerous requirements, as listed in Table 2. The residual mirror surface error over the clear aperture must be no more than 0.05 waves rms, and each mirror is an integral part of an LM1 cavity-mirror mount.

During Title I, we assembled 39-actuator “prototype” deformable mirror that met most of the NIF requirements and tested it on Beamlet. The prototype substrate material is BK7, with a hard dielectric coating having a reflectivity of ≥ 99.5% and a 1ω transmission of 0.2–0.5% at an angle of incidence of 0°. Figure 25 is a photograph of the assembled mirror.

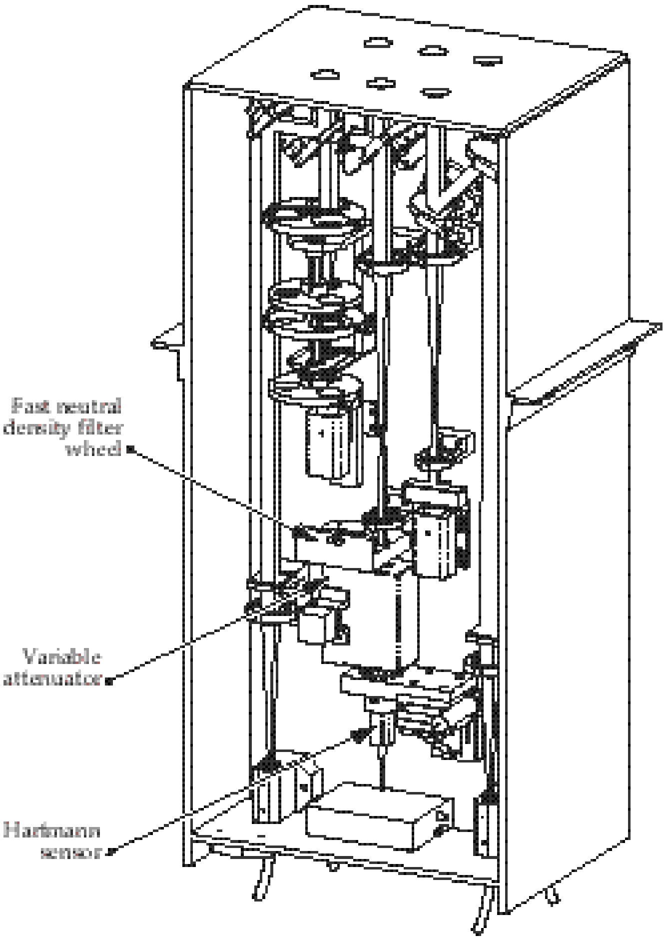


FIGURE 24. Location of the Hartmann sensor in the output sensor. (40-00-0398-0387pb01)

FIGURE 25. An LLNL 40 × 40 cm prototype deformable mirror has been assembled and tested. (40-00-1097-2267pb01)

TABLE 2. Actuator requirements for the NIF large-aperture deformable mirror.

Actuator requirements	
Stroke	15 µm (0.0006 in.) @ max. voltage
Material	PMN (electrostrictive formulation)
Electrodes	Platinum
Young’s modulus	>102 GPa (14 Mpsi)
Tensile strength	>24.1 MPa (3500 psi)
Stiffness	>250 N / µm
Hysteresis	<5%
Creep (max after 24)	<2%
Voltage range	0–200 V
Capacitance	15–30 µF (size dependent)
Frequency	>100 Hz (small amplitude)
Lifetime	$>10^9$ cycles

Title II Activities

In Title II, we will incorporate lessons learned from our prototype fabrication, assembly, and Beamlet operation. We plan to reduce the residual errors after assembly, if possible, and identify design changes that will reduce the cost without changing the performance. We will also work on improving the actuators, to increase their reliability at full voltage. In addition, we will begin qualifying vendors for production of the LLNL or equivalent design.

Wavefront Controller

The wavefront controller function is accomplished by systems that are modular at the eight-beam-bundle level. Each wavefront controller comprises computer hardware and software to periodically calibrate the associated Hartmann wavefront sensors and deformable mirrors, operate the automatic wavefront correction loops during preparations for a shot, and capture pulsed wavefront measurement data during a shot. In the moments immediately prior to a shot, the system is generally operated under closed-loop control to an offset wavefront value. This is because the flashlamp-pumped amplifiers introduce a dynamic wavefront change when they are fired, and the wavefront system must be set to anticipate that change.

Since the Hartmann sensor data is in video format, the controller incorporates image processing capabilities appropriate for recognizing and tracking the position of the 77 focused spots from each Hartmann image. The image processing code attains maximum accuracy by automatic adjustment of software parameters for grayscale and brightness. The controller also measures and applies the influence matrix for the deformable mirror actuators and the amplifier precorrection file in accordance with the mirror control algorithm. When operating in closed-loop, the controller is intended to maintain a closed-loop bandwidth of approximately 1 Hz on each beam.

The NIF wavefront controller hardware will use VME industrial computer bus and multiprocessor architecture designed to make maximum use of standard components and to accommodate replacement of modular elements as microprocessors and other computer electronics continue to evolve. The system will be attached to the Integrated Computer Control System network using CORBA (see p. 199).

Title II Activities

During Title II we will complete the hardware design including VME rack and laser bay wiring details, final circuit board layouts, and plans for production quantity procurement. The software specifications and controller design documents will be completed, and initial versions of the software will be written. Wavefront controller hardware and software will be tested both in a simulation system and in the wavefront control laboratory with the other components of the wavefront system.

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