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ABSTRACT

The NIF laser system will be capable of delivering 1.8MJ of 351nm energy in 192 beams. Diagnostics instruments must measure beam energy, power vs. time, wavefront quality, and beam intensity profile to characterize laser performance. Alignment and beam diagnostics are also used to set the laser up for the high power shots and to isolate problems when performance is less than expected. Alignment and beam diagnostics are multiplexed to keep the costs under control. At the front-end the beam is aligned and diagnosed in an input sensor package. The output 1053nm beam is sampled by collecting a 0.1% reflection from an output beam sampler and directing it to the output sensor package (OSP). The OSP also gets samples from final focus lens reflection and samples from the transport spatial filter pinhole plane. The output 351nm energy is measured by a calorimeter collecting the signal from an off-axis diffractive beam-sampler. Detailed information on the focused beam in the high-energy target focal plane region is gathered in the precision diagnostics. This paper describes the design of the alignment and diagnostics on the NIF laser system.

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 is 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 and process the diagnostic data 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 will 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,1/125 of beam spatial resolution

Table I. Tolerances for key alignment and diagnostics tasks

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Performance of alignment and beam diagnostic functions is accomplished by optical, electronic, and mechanical components distributed along each beam line. Fig. 1 identifies these components and illustrates the fact that the beam control systems

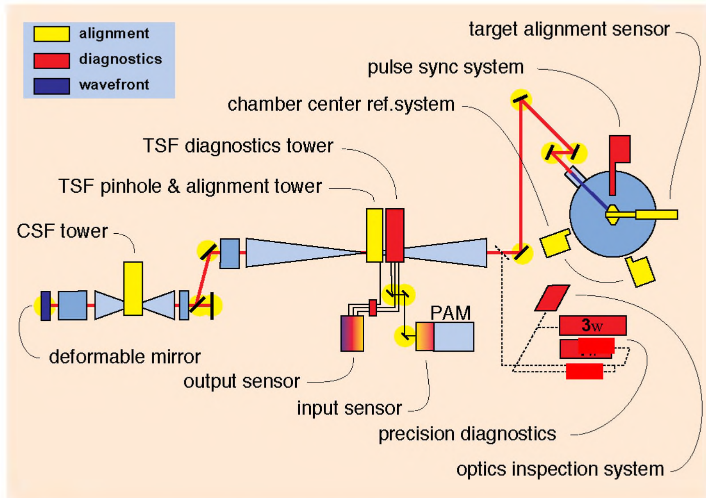


Fig. 1. Optical, electronic, and mechanical components distributed along each beam perform beam control functions. Towers near the pinhole plane of the cavity spatial filter (CSF) and the transport spatial filter (TSF) actually hold components for alignment and laser diagnostics functions on eight beams.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

have interfaces with every part of the laser. Other papers have addressed 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].

Input sensor package

The input sensor package, which is located at the output of the preamplifier module (PAM) as illustrated schematically in Figure 2, provides both alignment and diagnostics functions. The sensor using a CCD camera with nearfield or farfield lenses provides feedback for the alignment loops required to align the preamplifier module (PAM) into the preamplifier beam transport. The regenerative amplifier output in the PAM is used as the alignment source to align the PAM in to the preamplifier beam transport. The sensor also contains a CW alignment source that is shaped and aligned. This source is used to align the main laser cavity and provides a source to sample the wavefront of the laser chain for the wavefront sensor in the output sensor. The input sensor has the diagnostic functions to measure the energy, temporal and spatial waveforms. The energy measurement is carried out with an integrating sphere and photodiode followed by a charge integrator and digitizer. The temporal pulse shape sample is collected and launched into a fiber optic and transported to an external power sensor. Each power sensor multiplexes eight signals to minimize costs. The differences in signal levels between the alignment and the shot is the gain of the four pass amplifier (about 10e4) and can be accommodated with the electronic gain in the ISP diagnostics.

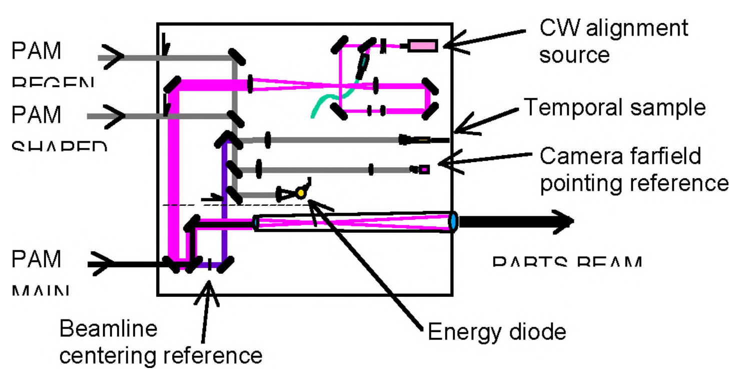


Fig. 2. The schematic of input sensor package shows how the beams are arranged to sample the PAM beams for alignment and diagnostics. The sensor also provides an alignment laser that is used for main cavity alignment and wavefront measurement.

Output sensor

The output sensor is located below the transport spatial filter at the end of a set of relay optics as shown in Fig.4. This sensor provides alignment and wavefront correction functions and characterizes the full beamline performance for a pair of beams. A beamsplitter is located immediately downstream from the output lens of the transport spatial filter (TSF). This beamsplitter reflects 0.1% of the TSF output back into the TSF. The tilt of the sampling surface is set such that the reflected light converges towards a pick-off located near the focal plane of the TSF. This pick-off reflects the sample out of the TSF vacuum vessel and into relay optics which carry it to the output sensor. This sampling technique illustrated in Fig. 3, uses existing large aperture main beamline optics to reduce the beam samples to manageable dimensions, and is used to collect both 1w and 3w samples. In the 1w case, the sample is collected off of the aforementioned beamsplitter, in the 3w case; the sample is collected off of the first, planar surface of the final focus lens.

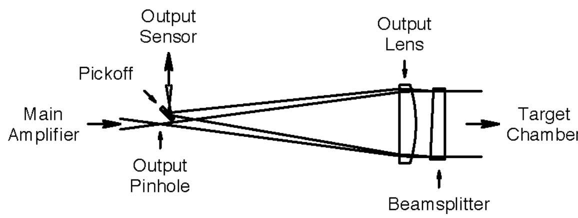
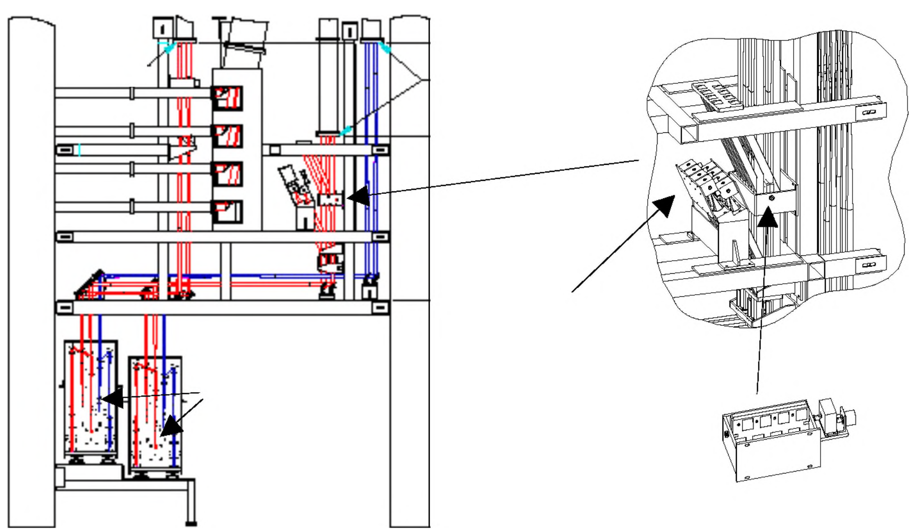


Fig. 3. A weakly reflective beamsplitter sends 0.1% of the TSF output back into the TSF. The tilt of the sampling offsets the reflected beam from the output beam so that a pick-off deployed near focus can direct the sample into diagnostics.

The diagnostic tasks performed by the OS completely characterize the output of the main amplifier, measuring wavefront, and recording spatial and temporal pulse shapes. It also records spatial and temporal pulse shapes of the 3w that reflects off of the final focus lens. Multiplexing is utilized to record the performance at a reasonable cost. The output of two Shack-Hartmann wavefront sensors can be fit onto a single 1/2" format CCD detector, so simultaneous measurement of the wavefront of both beams is accomplished. Two near field images are fit onto both the 1w and the 3w CCD cameras, so every beam is imaged every shot. Energy measurement is accomplished in the relay optics, where a beamsplitter in the1w beam path is used to direct a sample onto a photodiode assembly like that in the input sensor. Each beamline has a dedicated photodiode, so pulse energy is measured for every beam every shot. As mentioned above, samples of 1w and 3w light are sent to the power sensor. The power of one beam from every pair of beams is measured for each shot. This is the only OS diagnostic for which simultaneous use is not possible. CCD cameras image planes in the Target Bay by collecting light reflecting off of the final focus lens.

Fig. 4. Shows a Pro-E model of the area under the transport spatial filter. The beam samples are relayed to the output sensors. The fast attenuator allows the output sensor to sample the wavefront up to 1 sec before the main shot at which time it attenuates the high energy shot to levels that can be recorded. There is one energy diode for each of the beamline samples.



Wavefront correction

During preparations for a pulsed shot, the wavefront control system monitors the wavefront of each of the 192 main amplifier outputs and automatically compensates for measured aberrations using a full-aperture deformable mirror. There are static aberrations induced by optical fabrication and mounting. There are dynamic aberrations induced by flashlamp light at shot time, by residual heat in amplifiers after a shot, and from gas density gradients in the propagation path. In the last few minutes before a shot, the controlled wavefront is biased to include precorrections for the estimated dynamic aberrations caused by firing the flashlamp-pumped amplifiers. One second before a shot, closed-loop operation is interrupted, and the wavefront sensor is configured to measure the pulsed shot wavefront. The measured pulsed shot wavefront error provides additional information for setting precorrection prior to the next shot.

Configuring for the pulse shot evolves activating the fast attenuator in the relay optics to attenuate the pulse beam to a level that will not damage optics or break down the air at the focus of the relay optics. The fast attenuator is a fixed level of attenuation so there is an additional fast filter wheel in front of the wavefront sensor to trim the signal level to match the signal level required by the wavefront sensor.

The three main components of the wavefront control system are a Shack-Hartmann wavefront sensor, a deformable mirror, and a computer controller. The Shack-Hartmann sensor includes a 2 dimensional array of lenslets and a CCD video camera located at the back focal plane of the lenslets. The output sensor delivers a demagnified image of the main amplifier output to the lenslet array. The plane that is imaged is conjugate to the plane of the deformable mirror. Each lenslet collects light from a specific part of the beam and focuses it on the CCD. The position of each lenslet's focus on the CCD give a measure of the pointing of the small portion of the total beam that is incident on that particular lenslet. Directional data from the 77 hexagonally packed lenslets of the NIF sensor is 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.

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 mm ¥ 400 mm. Each deformable mirror serves as an end mirror for a main laser amplifier cavity. In this configuration, the mirror substrate and exposed components behind it are subjected to high fluence flashlamp light. The deformable must survive repeated exposure to 10 J/cm^2 pulses of flashlamp light. Each wavefront controller comprises computer hardware and software to periodically calibrate the associated 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. Since the Shack-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 sensor 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 bandwidth of approximately 1 Hz on each beam.

Cavity spatial filter tower (CSF)

The CSF tower contains CCD eight cameras that are used for alignment only. Each beamline has a camera that views a pointing reference in the pinhole plane during cavity spatial filter alignment. Since it is only used with the CW alignment source and the camera is blocked at shot time it's dynamic range requirements are small.

Precision diagnostics

Laser performance is measured for each beamline at the ISP, OSP, and the 3w calorimeter. To acquire more detailed information on the beam behavior of the high-energy focal region we have a precision diagnostic station. This diagnostic consists of a roving pick-off mirror at the output of the laser that can positioned to divert one beam at a time from the target chamber into the precision diagnostics. Any Final Optics Assembly (FOA) can be removed from the target chamber and placed on the precision diagnostics station. This station is connected to a vacuum chamber that has the capability of taking a full system shot and performs detailed diagnostics to examine the focal region. We can use this diagnostic to validate the main laser diagnostic measurement and gather addition data on the characteristics of the focal spot.

Final diagnostic package

The final diagnostic package is the 3w calorimeter. The final optics diagnostics uses a focusing off-axis diffractive splitter to obtain a 0.2% sample of the main beam for the 3w calorimeter. By measuring the 3w energy, this calorimeter calibrates the 3w beam power for each shot, inasmuch as the integrated 3w temporal pulse is set to equal the total 3w pulse energy.

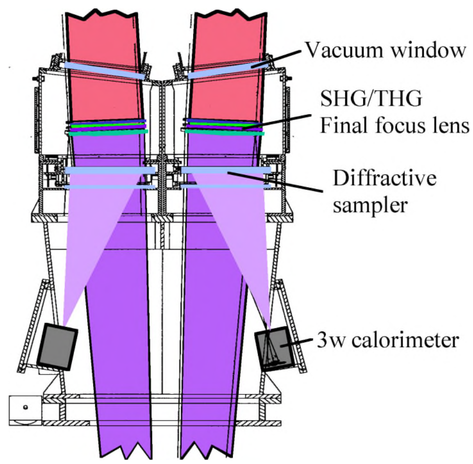


Fig. 6. The absorbing glass calorimeter in the FOA gets a 0.2% sample the 3w energy from an off-axis diffractive splitter. The sample is representative of the 3w energy on the target because the sample passes through all of the target path optics on it's way to the calorimeter.

Chamber center reference system/Target alignment system

The Chamber Center Reference System (CCRS), consisting of two high-resolution viewers mounted outside windows at orthogonal target chamber ports, provides a stable target chamber coordinate system. The position and orientation of the Target Alignment Sensor (TAS) in this coordinate system are sensed and automatically controlled for each shot. The TAS provides superimposed views of the target and the 3w beams without allowing any beams to preheat the target. A five-degree of freedom positioner is used to place the target in the center of the TAS, and the final transport mirror on each beam is controlled to position the beam at the desired position on the target.

2. SMALL OPTICS DAMAGE THREAT

The elements that are at the highest threat are the optics in the beam-sampling path for the output sensor. This is because we have a large range in signal between using the alignment beam and collecting data on the shot. As shown in fig. 3 we are using the output lens to downsize the beam sample to a size that is convenient to relay to the output sensor. The forward going beam and the sampled return beam are overlapped until just before the pick-off mirror and now the beam is small enough that damage is a problem. We can't decrease the splitter reflection because we need a splitter that we can fabricate and is stable with enough reflectivity to meet the alignment requirements. So all the optics from the pick-off to the fast attenuator has the highest damage threshold requirement.

The alignment and diagnostic sensors have been combined in the interest of controlling costs. This combining has increased the dynamic range over which the sensors and the relay optics must operate. The input sensor can work over this range because the total energy in the front-end is moderate. The output sensor on the other hand has to align using the CW source and then record data from the full power shot. This requires a fast attenuator to keep the sensor within its operating range.

Other alignment and beam diagnostics are not designed for shared operation and therefore can be designed without high damage threshold optics.

3. CONCLUSION

Design is proceeding successfully and is scheduled to be complete in fall of 1999. Construction and testing of prototype components is an important part of the design activity. The test results so far have been favorable, and first articles will be tested to verify performance. Procurement of production hardware has started in some systems and will begin for alignment and diagnostics at the end of 1999.

4. ACKNOWLEDGMENTS

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