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Laser chain alignment with low power local light sources

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ABSTRACT

Timely and repeatable alignment of the 192 beam National Ignition Facility (NIF) laser will require an automatic system. Demanding accuracy requirements must be met with high reliability at low cost while minimizing the turn-around time between shots. We describe an approach for internally self-consistent alignment of the mirrors in the laser chains using a network of local light sources that serve as near field and far field alignment references. It incorporates a minimum number of alignment lasers, handles many beams in parallel, and utilizes simple control algorithms.

Key words: alignment references, automatic alignment, fiber optics, fiber splitters, laser alignment, laser diodes, National Ignition Facility

1. NIF ALIGNMENT SYSTEM REQUIREMENTS

NIF alignment systems must meet a number of requirements. Foremost is the necessity to prepare a 192 beam laser facility to accurately illuminate a target on a short turn-around basis. By any measure this task is too large to be accomplished manually, so only alignment approaches that can be automated are of interest. Since cost and reliability are also important considerations, it is desirable to find an approach that minimizes alignment laser power requirements, allows multiplexing of a reduced number of alignment lasers, and minimizes the number of moving parts. Of course, there is an all-encompassing requirement to be compatible with other NIF systems, and this compatibility can be enhanced by taking advantage of existing components in other systems, i.e. sharing, or by designing systems to be independent and non-interfering. In particular, there is significant operational benefit in being able to work in the laser front end, main laser, and target areas independently while preparing for a shot.

A NIF light pulse propagating from the front end driver to the target interacts with more than 100 near-field optics and six far-field pinholes over a distance exceeding 360 meters. The tolerance assigned to near-field alignment accuracy to avoid clipping is 1% of the beam dimension, and the beam position in the last spatial filter pinhole must be controlled to about 1/7 of the diffraction limited spot size. The latter requirement is imposed by coalignment requirements between the main laser and the target area alignment beam that is inserted in the spatial filter pinhole plane.¹ Accuracy requirements at the other spatial filter pinhole locations are not as demanding, but in every case, performance must be independent of the pinhole size or condition.

2. NIF BASELINE DESIGN FOR CHAIN ALIGNMENT

The NIF baseline design includes a laser chain alignment approach that utilizes local light sources. Figure 1 illustrates the concept of local light sources as it relates to both far-field (pointing) and near-field (centering) alignment tasks. Adjusting mirror angles so that successive pinhole planes are imaged onto each other is equivalent to assuring that a beam passing through the center of one will also go through the center of the other. A local light source (far-field source) is inserted in the correct pinhole position in each pinhole plane. An alignment package at the chain output provides a view back into the chain when a pick-off mirror is inserted in the final spatial filter. With its optics configured for far-field viewing, the package collects an image of each of the pinhole plane light sources. The second local

source must be removed to see the light from the first, so they are not viewed simultaneously. However, the closed-loop controller saves the coordinates of each source image as it is observed. The coordinate difference of the two light source images is the error signal for pointing adjustment of the two reflectors between spatial filters.

Fig. 1. Local light sources provide a way to maintain self consistent alignment between the two parts of a NIF chain independent of activities in other parts of the laser system.

Additional adjustments of the same two mirrors are required to achieve superposition of pupil plane near-field images. Local light sources are permanently mounted outside of the main beam path but on the optical axis behind successive pupil plane locations. The light is again collected by the alignment package, but with the optics configured for near-field viewing. In this case, the two images are viewable simultaneously, but they can be switched on and off by the controller for separate measurement of their coordinates. The coordinate difference of the two near field light source images is the error signal for centering adjustment of the mirrors. The correct motor motions to achieve centering changes without disturbing pointing and vice versa are obtained by use of a cross coupling matrix in the controller. Because the alignment tasks illustrated in Figure 1 are accomplished with local light sources, there is no requirement for supporting activities in either the laser front end or the target area.

Extension of this general technique to the other two mirrors in the NIF large aperture amplifier chain is easily understood when the multipass characteristic of the chain layout is considered. Figure 2 is a perspective schematic of a NIF chain showing only the components required to explain alignment. As indicated by the arrows, the beam from the front end passes through a pinhole and continues on to the first of four passes in the multipass cavity. On each successive pass, the beam propagates in the opposite direction and goes through a different pinhole. Near the end of the fourth pass, it is switched out of the cavity and proceeds through a final pinhole to the target area. The pointing adjustment described in Figure 1 resulted in the imaging of cavity pinhole 4 onto the output pinhole 4.

Fig. 2. The NIF multipass chain design is based on propagation through a total of six pinholes. Four reflecting optics must be adjusted to complete chain alignment.

The two cavity mirrors must be adjusted before alignment of the laser chain is complete.

Figure 3 illustrates the imaging of cavity pinholes 2 and 3 onto output pinhole 4. To adjust cavity mirror 1, a local light source is inserted at the pass 3 location in the cavity facing in the pass 3 propagation direction. The light reflected off of cavity mirror 1 finds the pass 4 pinhole location open, is switched from the cavity, and viewed in the far-field by the output sensor for comparison with the light source in output pinhole 4. Overlap of the two light source images is achieved by tilting cavity mirror 1.

Adjustment procedures for cavity mirror 2 are entirely analogous and are illustrated in the bottom half of Figure 3. There is one complication, however. The Pockels cell that fires during pulsed operation of the chain to allow a laser pulse to remain in the cavity at the end of pass 2 is not fired during alignment. Unless the Pockels cell / polarizer function is altered, the light from the cavity pinhole 2 position is reflected from the cavity and does not reach the mirror being adjusted. Therefore, to provide for transmission of half of the local light source power on passes 2 and 3, the Pockels cell is temporarily tilted to the angle at which it functions as a quarter wave plate. This does not effect the far-field alignment accuracy.

Alignment of the laser front-end into the main chain and the procedures for positioning each frequency converted output beam on the target¹ are not described here, but they also make use of local light sources.

3. LIGHT SOURCE REQUIREMENTS AND OPTIONS

The NIF baseline design uses 11 light sources per chain at 1.05 μm or over 2100 light sources for the full 192 beam system. This includes the chain alignment devices specifically referred to in the previous section as well as those required for front end alignment and angle tuning of the frequency conversion crystals at the output. The power required ranges from 100 μW to 10 mW per channel. Control of the polarization is important for most of the sources because the laser chain amplifiers use Brewster angle slabs, and only P polarization is efficiently transmitted. In addition, the pointing sources are introduced inside of spatial filters so they must be vacuum compatible.

Fig. 3. Local light sources also provide images for maintenance of proper angle adjustment of the multipass cavity mirrors.

Finally, to avoid large losses in propagating through the system, the light source outputs must be matched to the laser system at the point of injection. Those used for centering references are expanded and collimated at approximately 1 cm diameter to support propagation over long distances without excessive divergence. Those used for pointing references are matched to the f number of the spatial filter in which they are injected. To gain maximum accuracy and ease of image processing, the sources should also be single mode to avoid speckle when they are imaged in the sensor packages. However, multimode options may be satisfactory in some cases.

It is possible that an individual discreet source such as a laser diode could be used at each light source location with suitable formatting optics. However, the concept we presently expect to use comprises fiber optic networks to distribute the output from a smaller number of sources to the full number of required locations. Figure 4 illustrates this approach. It incorporates miniature substrates with standard beam splitter coatings to reduce individual power levels below the fiber damage limits and then uses planar waveguide splitters in a fiber network.

Table I. is a summary of the 1.05 μm laser, fiber, and fiber splitter options we are considering. As the table indicates, some of the options require development. Trade-offs between development cost, procurement cost, and performance will contribute to a final choice.

Fig. 4. A fiber optic network is envisioned as the most cost effective way to implement the required number of local light sources and achieve high reliability.

Table I. Options for lasers, fibers, and fiber splitters at 1.05 μm

Laser type	Availability	Power/ laser(W)	Fiber type	Core or MFD(μm)	Coupler availability			Modulate polarization
Diode pumped solid state Nd:YLF	now	0.5 - 4	multimode	50 (0.2 NA)	1x2	1x4	1x8	yes
DBR laser diode	custom	0.050	single mode	6.4	*	*	*	yes
MOPA laser diode	custom (speculative)	0.5 - 1	single mode PM	7.2	*	1x4	1x8	no
Fiber (ytterbium-doped germanosilicate)	custom (speculative)	(0.3)	* Custom development required + Custom planar waveguide splitters acquired for evaluation					

4. FEATURES OF THE LOCAL LIGHT SOURCE APPROACH

For far-field alignment steps, images of the nearly diffraction-limited light sources are small in comparison with spatial filter pinhole images, which are 30 or more times diffraction limited and may have shape irregularities after many shots. Accordingly, video processing of the light source images is much easier, and the amount of power required to obtain a suitable signal level is lower by the ratio of the areas, a factor of 900 or more. With a spot dimension of 15 to 20 pixels, the most stringent far-field requirement of aligning to 1/7 of the spot is easily met. Not only is the power requirement at the CCD

small, but the power needed at the source is also low because it is injected without loss at the pinhole position and extracted without loss by an insertable pickoff mirror.

Near-field alignment also uses small images. The light source output is collimated at a diameter approximately 30 times smaller than the near field aperture. The ease of video processing and the light level required at the camera are therefore similar to the far-field images. With the field of view set to accommodate the full near-field aperture, the 1% of aperture accuracy requirement is even easier to achieve. In comparison to the far-field sources, the power of the near-field sources must be higher by a factor of 200 or more because the light is leaked into the chain through a highly reflecting coating. On the other hand, the near-field sources have the advantages of simplicity and mechanical reliability in that they are permanently positioned on the chain axis out of the main beam.

In both the near and far-field cases, the image quality is reduced if the laser chain optics exhibit aberrations. This effect is especially serious for the pinhole plane images. In the NIF baseline design, the problem is mitigated by the wavefront correction system with its full aperture deformable mirror at the end of the multipass amplifier cavity.² In this location, the mirror reflects the beam twice and its compensation of the aberrations in the chain is distributed in a way that approximates the distribution of the optics causing the aberrations.

The local light source alignment design allows many parallel operations. Beams whose alignment sources are derived from the same laser can still be aligned at the same time. In addition, all of the laser chain alignment steps are independent of both the front end and target area. This will be important for minimizing interference between multiple activities during the time between shots.

Prior to a system shot, the front end output must be aligned into the main amplifier chains. For that purpose, a light source centered on the front end apodizing aperture defines the near-field centerline. The pulsed laser front end provides low repetition rate full aperture pulses for far-field coalignment to the laser chain. Both sources can be observed by the same output alignment sensor that views the chain local light sources. For this step and all previous ones, the basic algorithm is the same: comparison of the image locations of small simple spots followed by a control motion to move one spot to match the position of the other. Additional functions are performed in the output sensor package including wavefront sensing for closed loop correction and other laser diagnostics measurements. Collocation and sharing of optical and video components help to contain the total cost of beam control and diagnostic systems.

5. LABORATORY SIMULATION OF ALIGNMENT WITH LOCAL LIGHT SOURCES

For purposes of evaluating some of the options in local light source alignment procedures and components, we have built a laboratory simulation of a NIF chain. In overall dimensions, the simulation is about 1/10 scale. However, the spatial filter optics are chosen to have the same f number as the actual NIF chain, and the diffraction limited spot size in the far-field is the same as for NIF. Accordingly, the pinhole spacings and sizes as well as the beam insertion and pickoff locations in the spatial filters can all be implemented at full scale. Figure 5 is a layout drawing of the laboratory simulation.

Components that do not influence assessment of alignment concepts and simulation of alignment procedures are not included in the scaled chain. For example, there are no amplifiers and no deformable mirror. To date this test system has been operated with 633 nm He-Ne light for both the main beam and local light sources. It will soon be converted to 1.05 μm for more realistic simulation and to allow the implementation of the 1.05 μm local light sources being developed for evaluation. Likewise, the initial adjustment of mirror mounts and insertion devices was done manually. However, motorized operation is implemented now, and closed-loop operation will be incorporated next year. Use of the laboratory will then be expanded to include software development.

From our initial work in the laboratory, we have gained an improved understanding of the differences in image characteristics associated with the use of single mode or multimode fibers. In addition, we have identified some strategies for initial set up of a NIF chain prior to activation of the automatic alignment systems. Work on these and other aspects of NIF chain alignment will continue.

Fig. 5. Laboratory simulation of the optical systems in a NIF chain provides a way to verify the suitability of proposed NIF alignment designs.

6. SUMMARY

Alignment tasks for the 192 beam NIF laser will require adjustment of some 14,000 actuators, many of them in automatic closed-loop systems. The conceptual design for alignment of the main laser chains utilizes low power local light sources as references with which to establish and maintain internally consistent adjustment of the laser chain. This is accomplished without access to light from the laser front end or instrumentation in the target area. Efforts are underway to validate NIF conceptual design alignment concepts on a scaled simulation of a NIF chain.

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