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TARGET PLANE IMAGING SYSTEM FOR THE NOVA LASER

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Abstract

The Nova laser, in operation since December 1984, is capable of irradiating targets with light at 1.05 μm, 0.53 μm, and 0.35 μm. Correct alignment of these harmonic beams uses a system called a target plane imager (TPI). It is a large microscope (four meters long, weighing one thousand kilograms) that relays images from the target chamber center to a video optics module located on the outside of the chamber. Several modes of operation are possible including: near-field viewing and far-field viewing at three magnifications and three wavelengths. In addition, the entire instrument can be scanned in X,Y,Z to examine various planes near chamber center. Performance of this system and its computer controls will be described.

Introduction

We have been conducting experiments at the Nova laser facility since December, 1984. These experiments require precise irradiation of small fusion targets at wavelengths of 1.05 μm, 0.53 μm, and 0.35 μm. Performance of the Nova laser has been described elsewhere.[1] This paper will describe the design and operation of a computer controlled target plane imaging system that we use to align the beams to targets. Figure 1 shows the target plane imager as it is mounted on the Nova target chamber. It is essentially a large microscope that relays images of the harmonic beams to viewing optics and a video sensor located in a module outside the chamber vacuum.

Target plane imager design

The system design was driven by the following requirements:

1. Provide remote viewing of focused laser beams at and near chamber center.
2. Provide near-field images of each full aperture 74 cm beam.
3. Perform this imaging at each of the three wavelengths.
4. Have sufficient sensitivity to form video images when viewing low intensity sources.

Figure 2 is an assembly drawing of the opto-mechanical subsystem that was designed to satisfy these requirements. There are two major portions to the assembly. There is the optical periscope that forms the images and relays them out of the chamber. It consists of an f/3 objective (eight elements), a one-to-one relay optic (four elements), and two field lenses. The second part is the viewing module that provides viewing capability at three magnifications of both the near-field and far-field images. These optical assemblies are mounted on an X,Y translation stage in order that a plane 50 mm X 50 mm at chamber center can be examined. In addition, all the optics (and the video camera) can be scanned in the Z direction to focus on any plane within ±25 mm of chamber center. Figure 1 depicts one of the laser beams reflected from the viewing mirror into the optical periscope. This is the operating mode used when forming near-field images of the beams. Each of the beams can be viewed by tipping the viewing mirror and rotating the periscope to the correct angles in order that the beam of interest is viewed directly. Optics in the viewing module allow examination of the beam at a plane just outside the chamber. This is where the 74 cm target focus lens is located as well as the KDP crystal array. Therefore, beam alignment to these and other elements of the system can be determined. In order to view far-field images, the viewing mirror is tipped out of the way and images of the beams focused on frosted reference targets are viewed directly. This is the most common operating mode.

First order design

The internal diameter, D, of the periscope assembly and its overall length of 3000 mm constrain the first order design parameters. Given an object 10 mm in diameter and a front objective magnification, M_1, the maximum diameter of the first internal image is equal to the tube diameter.

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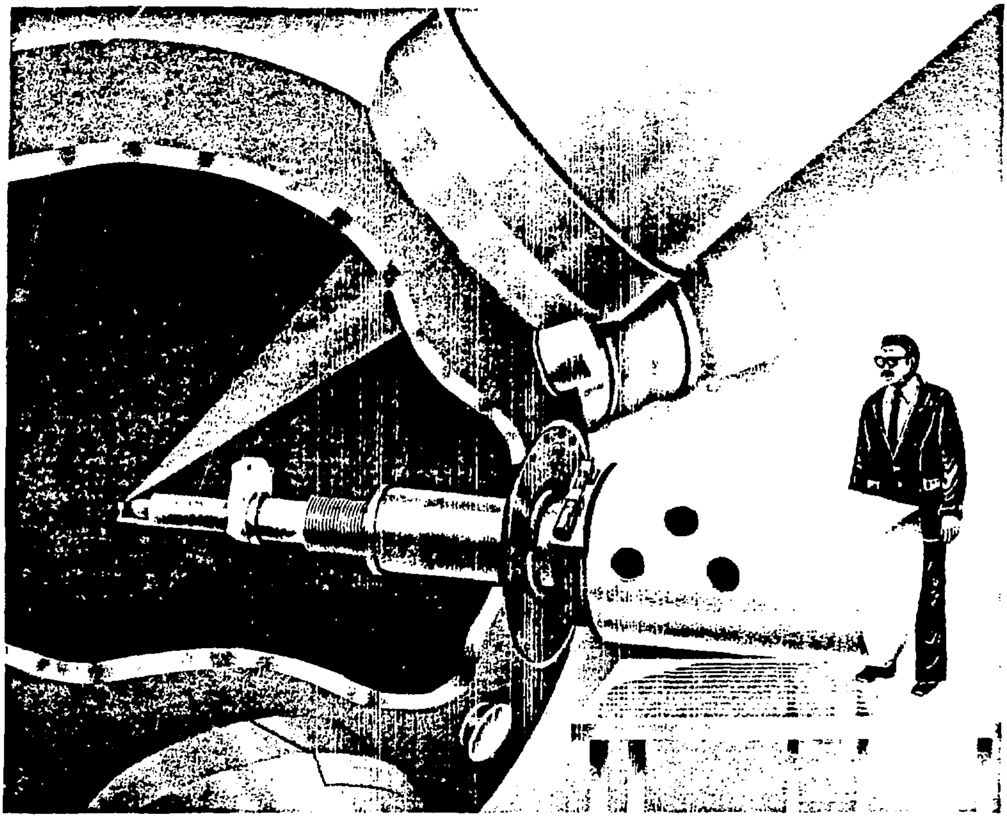

Figure 1. Nova target plane imager.

$$D = -M_1 \times 10 \text{ mm}. \tag{1}$$

For a front objective with focal length, f_1, the object and image distances are:

$$S_1 = f_1(1 - \frac{1}{M_1}) \text{ and } S_1' = f_1(1 - M_1).$$

The conjugates of the one-to-one relay are equal to S_1':

$$S_2 = S_2' = S_1' = f_1(1 - M_1).$$

The overall length of the periscope is given by:

$$3000 \text{ mm} = S_1 + S_1' + S_2 + S_2' = f_1 \frac{(M_1 - 1)}{M_1} + 3f_1(1 - M_1) = \frac{(M_1 - 1)}{M_1} f_1(1 - 3M_1). \tag{2}$$

The effective collecting f-number of the front objective is:

$$f_\# = \frac{S_1}{D} = \frac{f_1(1 - \frac{1}{M_1})}{D}. \tag{3}$$

We have generated three equations involving four unspecified parameters: D, M_1, f_1, and $f_\#$. Given a particular $f_\#$ value, we can solve for the remaining parameters.

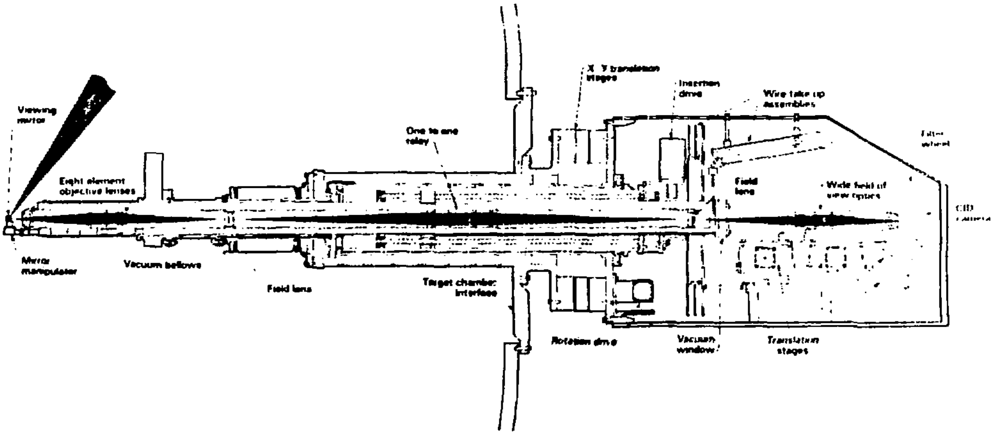

Figure 2. Nova target plane imager assembly drawing.

Equations (1) and (3) combine to give an expression for f_1:

$$f_1 = \frac{10\ M_1^2\ f_\#}{(M_1 - 1)}\ . \tag{4}$$

Substituting (4) into (3) yields:

$$3M_1^2 - M_1 = \frac{300}{f_\#} \qquad \text{or,}$$

$$M_1 = \frac{1 - \sqrt{1 + \frac{3600}{f_\#}}}{6} \simeq \frac{-\ 10}{\sqrt{f_\#}}\ . \tag{5}$$

Therefore:

$$D = -M_1 \times 10\ \text{mm} \simeq \frac{100\ \text{mm}}{\sqrt{f_\#}}\ . \tag{6}$$

Table 1 lists actual system values for several values of the collection f-number.

Table 1.

$f_\#$	M_1	D (mm)	f_1 (mm)	First Relay Length (mm)	Second Relay Length (mm)
2	-6.9	69	121	1092	1908
3	-5.6	56	143	1112	1888
4	-4.8	48	160	1130	1870

Therefore, an f/3 collecting system can easily be contained within a tube diameter of about 60 mm.

Achromatic vs. uncorrected chromatic

Although the periscope must operate at λ = 0.351 µm, 0.527µm, and 1.054 µm, there is no requirement for simultaneous imaging at all these wavelengths. This is fortunate, since an achromatic f/3 front objective would be quite complex. In order to ensure high optical throughput at 3ω, the front objective was designed using only fused silica. The objective is nearly diffraction-limited at all wavelengths, although the focal length changes slightly. A slight change in front conjugate, obtained by moving the entire periscope assembly, compensates for the shorter focal length at 0.351 μm.

The 1:1 relay, approximately 1900 mm long, is about 110 mm shorter at 0.35 μm than at 1.05 μm if it is made entirely of fused silica. Since it is mechanically inconvenient to compensate for this large change, this relay is an achromatic lens with equal length at 0.35 μm and 1.05 μm. The small field angle (+2°) and low f-number (f/16 in and out) permits the design to be implemented as back-to-back widely air-spaced telescope doublets. The Schott LF5 flint elements absorb less than 5% of the energy at 0.35 μm.

The two field lenses are also achromatic doublets so that the pupil is properly relayed through the system in the wide field-of-view mode.

Details of the optical design are included in Figs. 3 and 4 and Table 2.

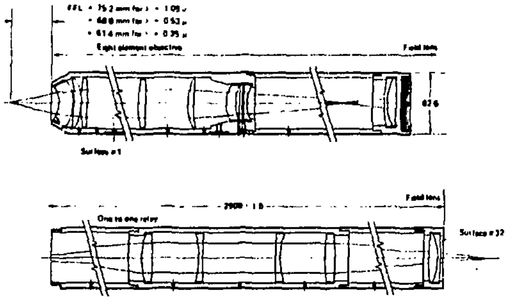

Figure 3. Nova target plane imager periscope optics.

Table 2. Optical Design Parameters

Lens Assembly	Element Number	Radius of Curvature	Axial Thickness	Material
Eight Element Objective	1	-36.61	19.66	Fused Silica
		-53.16	0.20	Vacuum
	2	-148.79	10.00	Fused Silica
		-73.00	1.00	Vacuum
	3	330.12	9.00	Fused Silica
		-220.44	237.73	Vacuum
	4	220.44	9.00	Fused Silica
		-330.12	57.88	Vacuum
	5	96.89	9.00	Fused Silica
		353.90	45.34	Vacuum
	6	53.16	12.79	Fused Silica
		73.00	5.00	Vacuum
	7	-351.90	4.00	Fused Silica
		220.44	2.00	Vacuum
	8	Plano	4.77	Fused Silica
		53.16	-	Vacuum
Field Lens	1	225.78	4.44	LF-5
		82.53	-	Cement
	2	82.53	12.22	Fused Silica
		-225.78	-	Vacuum
One-to-one	1	160.35	14.73	Fused Silica
		-313.19	62.26	Vacuum
	2	-140.72	6.03	LF-5
		Plano	101.63	Vacuum
	2	Plano	6.03	LF-5
		140.72	62.26	Vacuum
	1	313.78	12.22	Fused Silica
		-160.35	-	Vacuum
Field Lens	2	225.78	12.22	Fused Silica
		-82.53	-	Cement
	1	-82.53	4.44	LF-5
		-225.78	-	Vacuum
Wide FOV	Reverse of eight element objective			
Medium FOV	1	176.50	6.0	LF-5
		82.53	0.81	Air
	2	82.53	9.0	Fused Silica
		-500.80	98.35	Air
	2	500.80	9.0	Fused Silica
		-82.53	0.81	Air
	1	-82.53	6.0	LF-5
		-176.50	-	Air
Narrow FOV	1	137.80	4.0	LF-5
		48.40	1.354	Air
	2	48.40	8.4	Fused Silica
		-119.90	-	Air

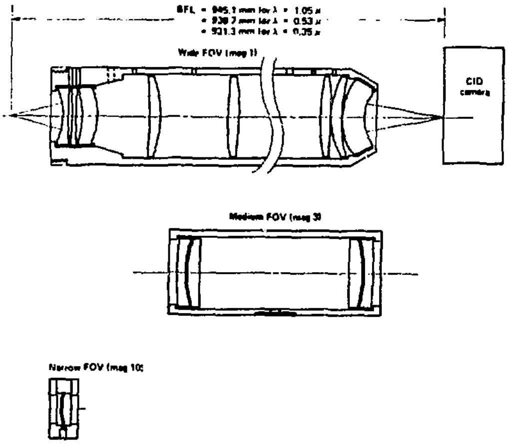

Figure 4. Nova target plane imager far-field viewing optics.

Performance

The input to the target plane imager was made fast (f/3) in order to achieve high resolution and high sensitivity. In operation, the limiting factors on resolution are the graininess of the diffuse alignment reticles used and the CID resolution. Even so, we have been able to resolve 7 μm features and position focal spots to an accuracy of ±15 μm. Although this could be improved by using more sophisticated image analysis techniques, it has proven satisfactory for our application.

System sensitivity is determined by the signal-to-noise ratio in the CID cameras used, the solid angle of the instrument input, and the scattering characteristics of the reticles used. Since the target plane imager is effectively an f/3 system, the input solid angle is about 8.5×10^{-2} steradians. Laboratory measurements have determined that the minimum detectable signal (signal-to-noise ratio of 1) for the CID camera used is 2×10^{-7} W/cm^2 at 1.05 μm, 1×10^{-7} W/cm^2 at 0.53 μm, and 1×10^{-5} W/cm^2 at 0.35 μm (on the chip). Scattering characteristics of the reticle material have been measured also. When a beam is incident on the frosted glass at an angle of 45%, 35-40% of the light is scattered forward into angles less than 15°. About 50% of the light is scattered forward into a lobe pattern that can be approximated by:

$$R\ (\theta) = \frac{7\ Ps}{2\pi}\ \cos^6\ (\theta)\ \text{watts/sr}$$

where Ps is about 50% of the incident power. In addition, 10-15% of the light is scattered into a similar pattern centered on the direction expected for specular reflection. The result is that the target plane imager can view and align focused beams with a power of about 10^{-8} watts incident at chamber center for 1.05 μm and 0.53 μm and about 10^{-6} watts at 0.35 μm.

System operation

Alignment of the laser beams and the fusion target prior to an experiment is accomplished using several interdependent subsystems at the target chamber.[2] Figure 5 includes these in block diagram form. There are three target alignment viewers that determine an orthogonal reference frame in which target positions are measured. A typical alignment procedure involves positioning a reference reticle near chamber center using the alignment aid positioner. The precise reticle location depends on details of the target. Next, the laser beams of the correct wavelength are focused onto the reference reticle as determined by the target plane imager. Finally, the reference reticle is removed and a fusion target is precisely aligned to chamber center using the target positioner. At this point all the viewing instruments are commanded to safe configuration before the target is irradiated.

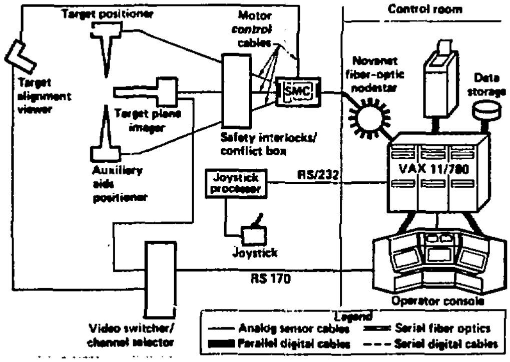

Figure 5. Nova manual target alignment controls.

Computer controls of Nova target positioning devices

The control system for target positioning devices is resident on two computers:

1. an LSI-11/23 microcomputer stepper motor controller (SMC); and
2. a DEC VAX-11/780 which is used to run operator interface software.

The operator remotely commands the target positioning devices through a series of touch screen menus displayed on a touch sensitive graphics video display (Fig. 6). When the operator issues a command by touching the corresponding menu button, the VAX-based software reads a configuration file containing a list of the devices and setpoints to move to complete the operation. Each target positioning device can have ten defined setpoints. Each setpoint has a table of motor positions corresponding to it stored in the SMC. The commands are issued to the SMC across the local area network and the status of the completion reported back to the operator by updating the color of the chosen button on the menu.

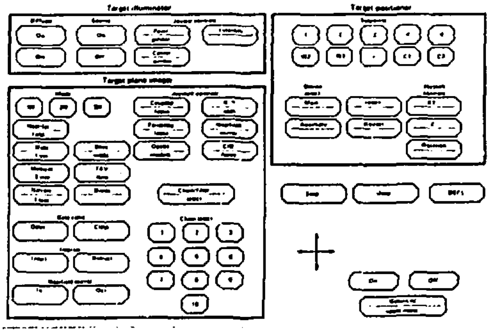

Figure 6. Nova target chamber alignment touch panel.

Having these commands file-based instead of coded into the operator interface software eliminates the need to recompile when a change occurs in a positioning sequence. The operator would simply edit an ASCII file containing English-like commands which will then be used as the new configuration file during subsequent command operations. The configuration file schema allowed us to develope complex motions on multiple devices without a lengthy software development effort.

The VAX-based software also provides manual control for dynamic alignment functions such as final target positioning. A joystick is used to enter direction and rate simultaneously for fine resolution slewing of device motors in two axes. The joystick has finer resolution at the slower slewing rates to make small adjustments easier. Cross-coupling of motor coordinates is provided such that the observed image motion tracks the joystick motion. After the operator completes an adjustment to a target alignment device, he may then declare this new position as a setpoint. The new motor positions are updated in the SMC setpoint table, which provides the operator with the flexibility to move from this position and return with a single command.

The SMC design is based on the alignment device, a collection of stepper motors that are related in alignment function. The SMC provides a local control panel with switches and programmable alphanumeric displays which reflect the changeable function of each switch.

The ability to command groups of motors as a single device allows the operator to customize both local control panel and remote commands. A reservation system has been implemented to prevent conflicts that result from two or more operators trying to use the same device for dissimilar tasks at the same time. In addition to the software reservation system, the target alignment devices are hardware interlocked overriding any command sent which has the potential to cause a collision. The interlock system uses contact switches on the alignment devices to sense position and matches these positions with a ROM stored truth table. If the interlock system detects a potential collision, it immediately cuts the power to the motor in the direction causing the conflict. The operator would then have to "back out" the device to correct the conflict situation.

Conclusions

During the past year, we have been using a target plane imager system to align the Nova laser beams. Operating at the focal point of the entire laser system, it has access to most of the alignment information present. Therefore, it has proven to be one of the system's most valuable optical instruments. Its most important use is the routine alignment of harmonic beams prior to target shots.

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