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Spatial Filter Lens Design for the Main Laser of the National Ignition Facility

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Spatial filter lens design for the main laser of the National Ignition Facility

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ABSTRACT

The National Ignition Facility (NIF), being designed and constructed at Lawrence Livermore National Laboratory (LLNL), comprises 192 laser beams. The lasing medium is neodymium in phosphate glass with a fundamental frequency (1ω) of 1.053μm. Sum frequency generation in a pair of conversion crystals (KDP/KD*P) will produce 1.8 megajoules of the third harmonic light (3ω or λ=0.351μm) at the target.

The purpose of this paper is to provide the lens design community with the current lens design details of the large powered optics in the Main Laser. This paper describes the lens design configuration and design considerations of the Main Laser. The Main Laser is 123 meters long and includes two spatial filters: one 23.5 meters and one 60 meters. These spatial filters perform crucial beam filtering and relaying functions. We shall describe the significant lens design aspects of these spatial filter lenses which allow them to successfully deliver the appropriate beam characteristic onto the target. For a broad overview of NIF, please see, "Optical system design of the National Ignition Facility," by R. Edward English, et al, also found in this volume.

1. SPATIAL LENS DESIGN CONFIGURATION

To help identify the operational subassemblies in the Main Laser, refer to Figure 1. As depicted, the Main Laser has two spatial filter (SF) assemblies: the 23.5-meter Cavity Spatial Filter (CSF) and 60-meter Transport Spatial Filter (TSF). The powered optics in the spatial filters (grayed portions of Figure 1) are the subject of this paper.

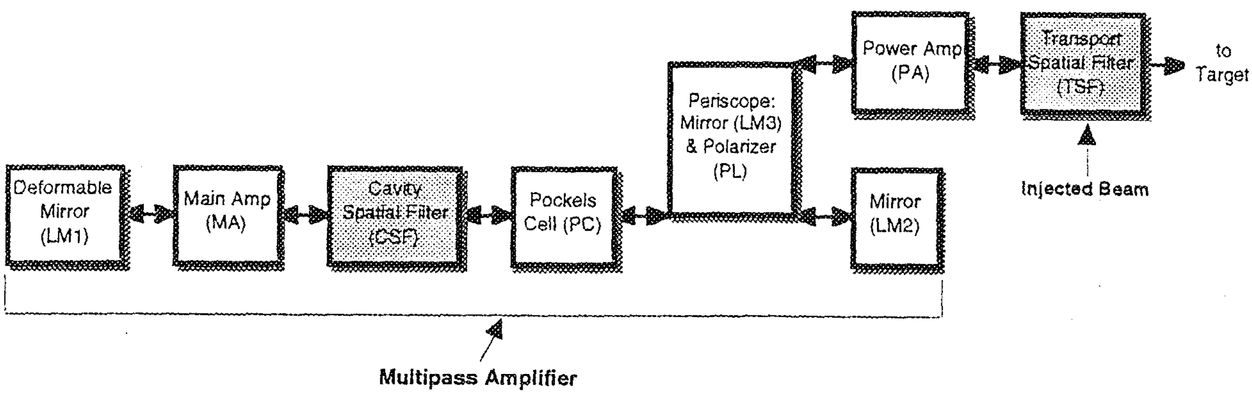


Figure 1 Block diagram of NIF Main Laser Subassemblies

The spatial filter lenses are only singlets, but they have many demands on them. Being singlets, they only have a few variables to work with to perform their functions and satisfy the optical requirements. The functions the spatial filters must provide in the Main Laser are listed in Table 1.

* This work was performed by OPTICS 1 as part of the Science Applications International Corporation Master Task Agreement for optical engineering support to LLNL on the NIF project.

Specific requirements flowdown to the SF design from the functions, the laser configuration, and the required packaging. A brief description of a beam path through the Main Laser for one of the 192 beams is as follows. A two joule beam is injected near the midpoint of the TSF and aimed back towards the multipass amplifier through TSF Pinhole 1. The beam passes through the power amplifier (PA) on its way to the multipass cavity. The beam then enters the multipass cavity and makes four passes through the Main Amplifier (MA). Switching the beam in and out of the multipass amplifier cavity is done with with the Pockels cell. On the way back to the TSF, the beam passes a second time through the PA. The TSF filters the beam and relays it to the Switchyard (SY) directed to the focus lenses (FL) around the target chamber. The salient lens design features are as follows.

I. Primary functions
- A. Cavity (CSF)
  - 1. 1:1 afocal relay of LM1 to LM2
- B. Transport (TSF)
  - 1. Collimate injected beam
  - 2. 1:1 afocal relay
    - a) Image pupil to proper location for Cavity Spatial Filter
    - b) Image pupil to acceptable position w.r.t. final optics
- C. Spatially filter the beam by focusing through pinholes
  - 1. Obstruct major high-angle components
- D. Provide vacuum barrier to prevent breakdown at focus

II. Interface functions
- A. Provide signal for wavefront diagnostic
- B. Accommodate final optics alignment reflection

Table 1 Spatial Filter functions

- The beam does not go through the center of the spatial filter lenses
  - The beam traverses the TSF in a two dimensional field-of-view manner
  - The beam traverses the CSF in a three dimensional field-of-view manner
- Pupil images are located at LM1 and LM2 and between the PA and LM3

The explicit and derived requirements of the SF lenses are summarized in Table 2.

The Main Laser beam path has been modeled on lens design software. Several software codes have been used in developing the software model and checking the results. In the Main Laser software model, many of the components and subassemblies have been positioned relative to a NIF global coordinate system. Global modeling has made it easier to update components to the Main Laser Optical Configuration Drawings as the design has been refined since key component positions are described in the NIF global coordinates in the drawings. The global positioning also was useful in two other aspects of the software modeling: (1) implementing the multipass Main Amplifier system relative to the Power Amplifier and TSF section and (2) the implementation of the optical aspects of the online pointing and centering functions of the laser.

I. Limiting optical clear aperture in the 1ω laser is the amplifier

II. Damage threshold (scaled to 3 nsec Gaussian pulses)
- A. SF1 13.0 J/cm^2; SF2 11.7 J/cm^2; SF3 20.8 J/cm^2; SF4 23.2 J/cm^2

III. Transported beam wavefront to meet wavefront error & waviness allocations

IV. Focal length
- A. Chosen to create 1:1 image of LM1 onto LM2
- B. TSF shall be 30 meters to match building packaging

V. TSF input lens shall have a ghost keepout zone of 0.2 x focal length

VI. SF lenses shall have a peak stress <500 psi under vacuum load

VII. Material: fused silica

VIII. Pinhole spacing in TSF: 35 mm
- A. Pinhole angular acceptance is ±100 μrad
  - 1. Allow for increase to ±200 μrad

IX. Spatial filter lens designs will allow for ghost control

X. SF4 is centered on exit beam

XI. TSF shall provide a full aperture reflected beam sample with uniformity, intensity, and wavefront quality as required by output sensor system
- A. Via Diagnostic Beamsplitter plates after SF4

XII. Be easily replaceable for maintenance

Table 2 Spatial Filter requirements

Even though key components were located globally, the software model of the Main Laser was done sequentially through the components to more easily extract beam center information on the components for the various times the beam passes through the individual components. Some other features used beyond globally locating key components in the software model are pickups and surface labels. Extensive parameter pickups were employed in order to facilitate updating the values as the design was modified. Numerous surface labels are used both as an identifying road map in the extensive model and as a means of analyzing and optimizing the system in a "generic" fashion, i.e., as the surface count increased, analysis calls do not have to be changed. Some of these modeling aspects have been incorporated in the Main Laser software model as the capabilities were made available by the software vendor during the course of this effort.

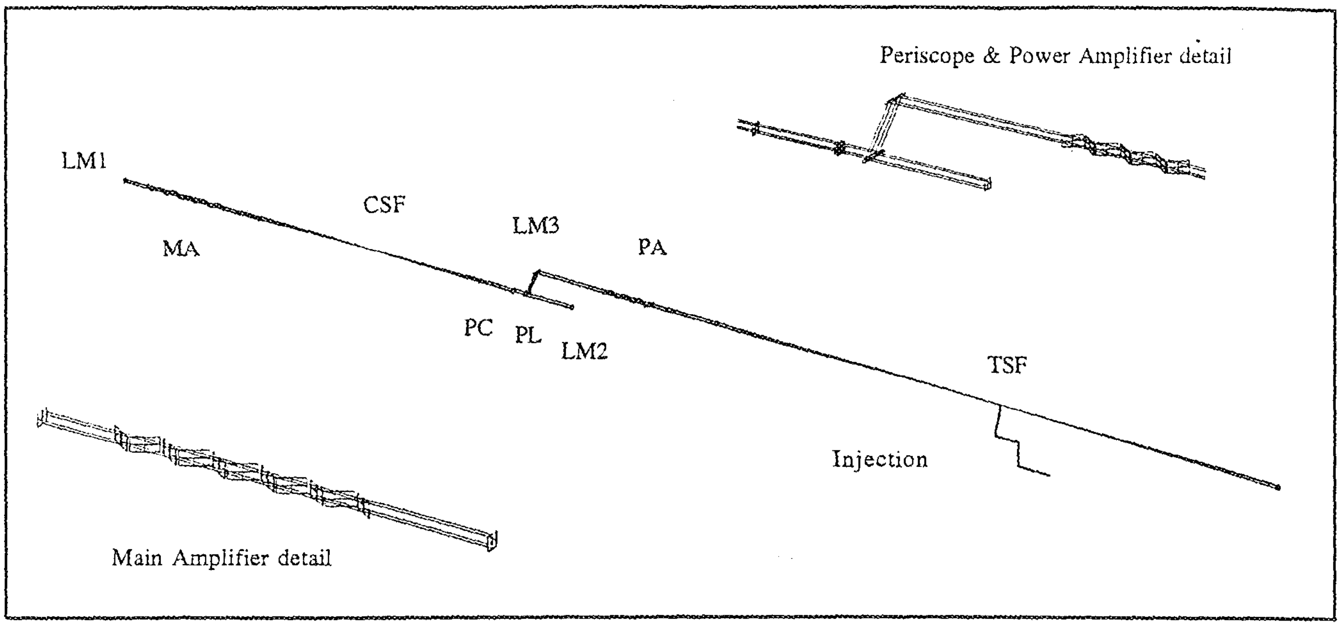


Figure 2 A Main Laser beam path

Figure 2 illustrates the Main Laser beam path starting from an Injection System. The size of the Main Laser beampaths dwarfs the nominal aperture size (372 mm x 373 mm) of the beam. The insert provides more clarity of the components outside of the SF relays.

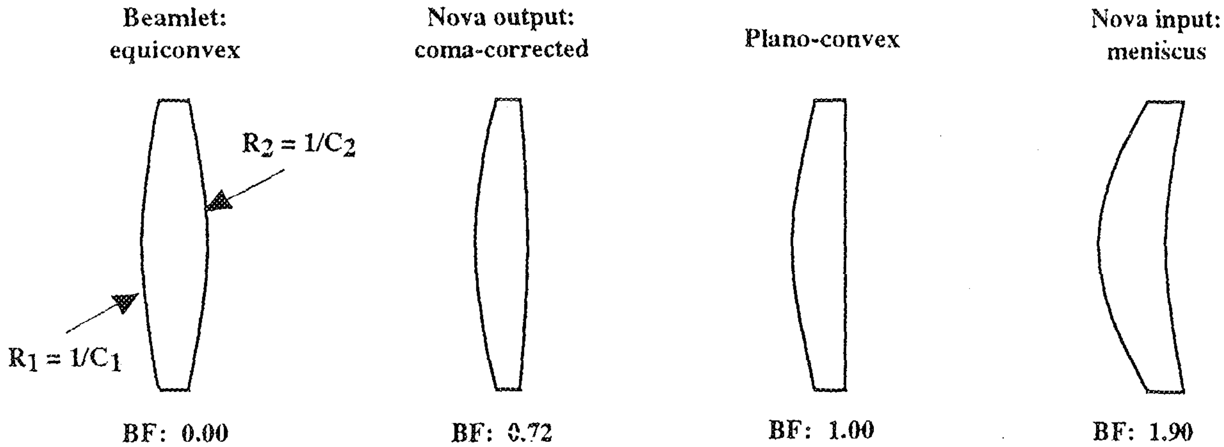
2. LENS DESIGN CONSIDERATIONS

Cost, space constraints, aperture size, vacuum load, and ghost reflections are major lens design drivers of the Main Laser. A major cost of the project is the building that houses the laser. The smaller the building, the lower the cost impact of the structure needed to house the laser. One of the main ways of reducing the size of the building is to do the amplification of the beam in a multipass configuration through the amplifier glass. Another way is to place the beamlines as close together as possible. To achieve a close-packed situation, the apertures of the components are square (actually they are slightly rectangular).

The spatial filter lenses serve several purposes at once—optically and structurally. First, they "clean" the beam of higher-order diffraction effects caused by surface and material imperfections; second, they relay the effective pupil location in the system to strategic components; and finally, they are the physical end components on the SF vacuum vessels that house the pinholes. Since the SF material choice is limited to silica, the design variables for the elements are the surface shapes; as will be seen, spherical surfaces are too limiting.

Ghosts in a high-energy laser can cause catastrophic failure of components if not managed properly. The vacuum vessels typically have beam dumps to eliminate unwanted ghosts. The components in a vacuum outgas over time. The degree of outgassing is increased when the components are heated. The beam dumps and baffles in a vacuum vessel are purposely struck by beam reflections to eliminate unwanted propagation. Depending on the situation, some ablation may occur. During operations the SF lenses will need to be refinished. Therefore, the vacuum-side surface of the SF lens is a spherical shape to aid in the reworking of the surface. The Main Laser SF lenses are planned for four maintenance resurfacings.

The polarization properties of the beam need to be maintained throughout the amplification process. The efficient switching and amplification depend on the proper polarization. One potential source that could alter the polarization properties of the beam is the stress birefringence that occurs at the SF lenses. From experience and analysis, the best shape to minimize stress birefringence is to have the SF lenses equiconvex (Figure 3), though it is not the best shape for wavefront quality or mounting sensitivity.



Lens bending factor (BF): $BF = \frac{C_1 + C_2}{C_1 - C_2}$

Figure 3 SF bending choices

These prescription limitations on the SF lenses leave little to control the primary aberration in the system, spherical aberration, or to minimize the sensitivity of mounting the elements (a coma-corrected shape). Since the wavefront error budget is demanding in a beamline, because of the hundreds of optical surfaces that the beam encounters, many refractive components in the NIF laser have at least one aspherical surface—typically a conic shape.

Ghost origination can be full aperture or subaperture (pencil)—the latter being the most insidious. Full-aperture ghosts are managed by keeping structure and equipment out of the way of the reflection (keepout zones) and are mitigated to a certain extent by the antireflection coating on the ghosting surfaces. With the initial fluences being so high and the concentrating effect of the ghost beam focusing, full-aperture ghost "hunting" is required to at least the third level of reflections off surfaces in the immediate vicinity with lens-design software, see Figure 4a. This level of ghost busting is useful in justifying the safety of the initial component placements. Higher level ghosts or ghosts off more remote components are evaluated with radiometric analysis software.

The other source of ghosts is not readily anticipated and is very sneaky—pencil ghosts, see Figure 4b. Pencil ghosts arise from a full aperture ghost illuminating a pinhole. The portion of the full-aperture ghost (now a pencil ghost) that makes it through the pinhole can propagate back through the system picking up energy as it goes back through the amplifiers. These ghosts are the hardest to investigate and control. A thorough ray trace of the laser design with a radiometric analysis software is needed to find and manage pencil ghosts so that they can be eliminated before they cause serious damage to the laser.

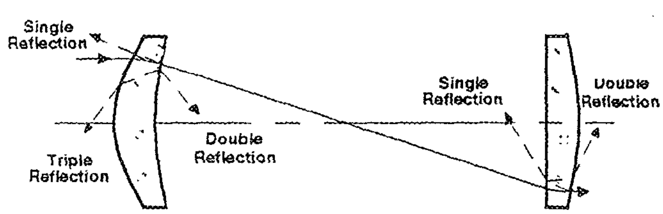


Figure 4a Ghostdepth

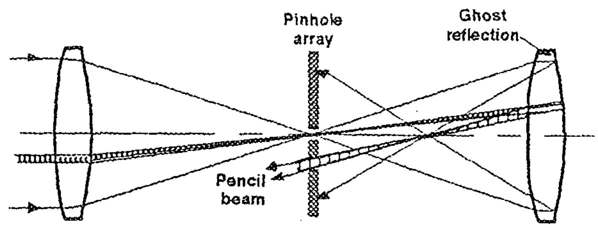


Figure 4b Pencil ghost

The most efficient method of totally eliminating pencil ghosts and high-fluence full-aperture ghosts is to tilt the element. The offending full aperture ghost is deflected entirely away from the pinhole that would create a pencil ghost. Tilting flat surface refractive components is no problem. However, if the element is a SF lens, then the aberrations, introduced by the tilt, have to be corrected. In the NIF Main Laser, the TSF lenses are tilted 2.8° for two reasons: (1) to eliminate the pencil ghosts initiated from these full-power surface reflections and (2) to deflect the focusing ghost reflections on the outside of the vacuum vessel away from components that can't be moved (their positions were determined when the building size was chosen). Figure 5 illustrates the elimination of the SF3 ghost that would have focused on laser slabs in the Power Amplifier subassembly (PA). Consequently, the airside surface of the tilted SF lenses (SF3 & SF4) needs to be a special aspherical surface—a bilaterally symmetric asphere (BSA).

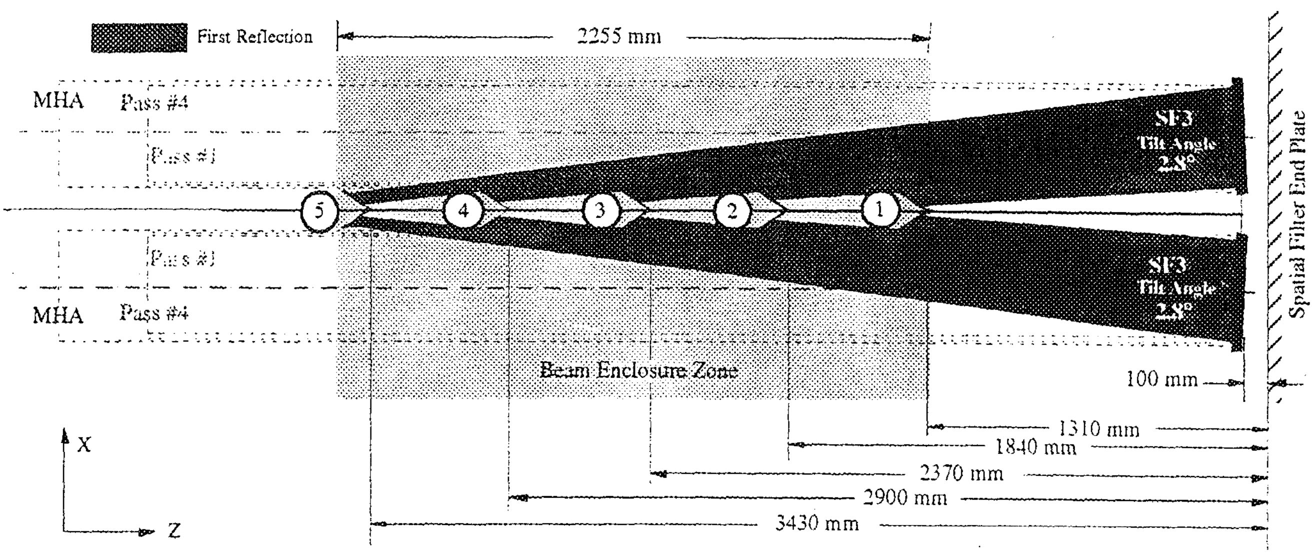


Figure 5 SF3 baffling near Power Amplifier (PA)

The initial layout of a laser, as is done in many new configuration lens designs, is a paraxial model. A paraxial model is very informative about the first-order nature of an optical system. However, a paraxial model lacks the detail needed to refine the design to account for subtle effects. Small angular deviations over the large distances of the Main Laser optical train can amount to lost energy and can cause beam intensity modulation resulting in damage to components—aging them prematurely or potentially causing catastrophic failure. One such deviation arises from the beam traversing the tilted TSF lenses which is a vacuum-air interface. Two effects that occur here that add a slight angle to the beam: (1) the difference in the immersion medium on either side of the SF lens (Figure 6) and (2) the center of the beam does not see the identical portion of the surface profile on both sides of the lens because of the asphere.

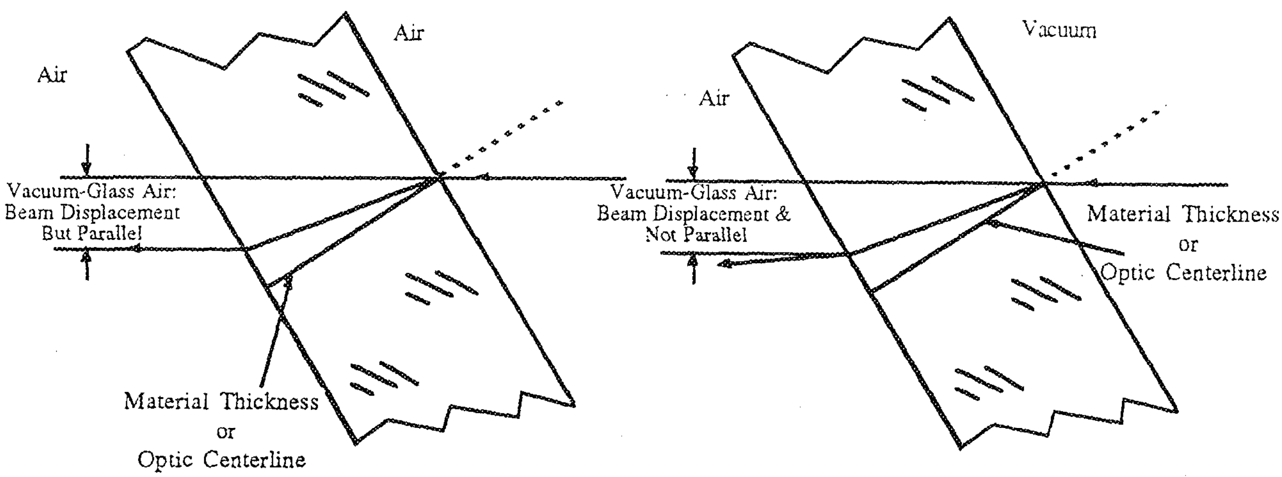


Figure 6 Air-vacuum beam deflection about a plane parallel plate

Another aspect of the laser design is that the amplifiers are plane parallel plates of laser glass. The laser glass is tilted at Brewster's angle for efficient coupling with the polarized light. These plates are located in a collimated portion of the laser system as far as the wavefront model (far-field model) is concerned. However, the other aspect of a SF lens set is to relay the pupil to specific components in the system. In the pupil model (near-field model) the tilted plates are in a convergent space. Therefore, the tilted plates add astigmatism to the pupil imagery splitting the location of the focus of the pupil object. There is also the possibility of variation of astigmatism with pupil object height. This higher-order effect is not considered in the paraxial model.

An additional complication is how to define the location of the entrance pupil to the CSF multipass system with that of the exit pupil, since the beam experiences additional amplifiers in the CSF. Therefore, the exit pupil of the CSF has more astigmatism associated with it than the entrance pupil. This aspect of the real beam is an important consideration in the nominal model when the pointing and centering of the alignment system is taken into account. This condition is addressed by having the pointing and centering control the crossover point (the location where the center of the entering beam is crossed by the center of exiting beam) regardless of the change in pupil astigmatism. This location is not at the paraxial location of the pupil—an important aspect to be quantified in advance for the online pointing and centering system.

A summary list of some other nonparaxial design adjusts that have been quantified with optical software models is as follows.

1. SF3 was nominally decentered to set the TSF pinhole spacing to 35 mm
2. SF4 was nominally decentered to have the beam go through its aperture center based on the real ray Pass 4 return angle in TSF
3. PA was moved up 6 mm to better accommodate a 1ω return ghost from the target
4. The tilt adjustable components were reorientated to position the beam foci in the CSF
5. Aperture location adjustments were made at LM3, PL, and LM2 to optimize their aperture utilization
6. SF design refined for air-vacuum focus impact
7. Design of the bilaterally symmetric aspherical prescription on SF3 and SF4 with best-fit sphere base to match vacuum-side spherical radius
8. Design of the conic aspherical shape prescription on SF1 and SF2 with best-fit sphere base to match vacuum-side spherical radius
9. Determine the nominal exit angle and exit lateral location relative to the TSF mechanical axis
10. Relocation of the Pockels cell, periscope, and LM2 by 120 mm because of a ghost

3. SPATIAL FILTER LENS DESIGNS

The Main Laser has many optical components, but only two different imaging spatial filter design prescriptions. Both components are large-aperture singlets made of fused silica. Details of the final designs, are described next.

SF1 and SF2 (SF1/2)

The CSF is a 23.5-meter spatial filter 1:1 relay made up of SF1 and SF2. SF1 and SF2 have the same prescription, and the component is referred to as SF1/2. The main imaging purposes of the SF1/2 pair is to relay the pupil onto LM1 and LM2 during the four passes the beam makes through the CSF. However, the fact that the beam goes through the relay four times, the amount of the pupil astigmatism increase each time the beam goes through the MA tilted slabs. Though the pupil is split with astigmatism, the depth of focus of the beam is much larger than the pupil astigmatism, so no significant near field intensity fluctuation is anticipated.

To minimize the wavefront aberration introduced by the equiconvex vacuum interface lenses, SF1/2 has a conic asphere on the airside surface. The base curvature for the aspheric surface was designed to be the best-fit-sphere (to the corner of the component)

- Size
  - 438 x 434 x 46 mm
- Optical clear aperture
  - 406 x 406 mm
- Mechanical hard aperture
  - 409 x 409 mm
- Shape & radii
  - equiconvex w/ an asphere & 10,590.51 mm
- Aspherical
  - Air-side conic asphere
  - Conic constant: -5.943
  - Best-fit spherical sag departure: 0.00139 mm
  - Base radius of curvature: 10,577.26 mm
- Material
  - Silica
- Back focal length (vacuum @ 1.053μm)
  - 11,751.5 mm
- Field-of-view usage & RMS wavefront error to periscope
  - 0.047° & 0.013 wave—diffraction limited
- Nominal tilt angle w.r.t. mechanical axis
  - None
- Relay magnification
  - 1x

Table 3 SF1 & SF2 Details

and made to match the spherical radius on the other side. Prescription details are found in Table 3.

SF3 and SF4 (SF3/4)

The TSF is a 60-meter spatial filter 1:1 relay made up of SF3 and SF4. Though they were not this way initially, SF3 and SF4 have the same prescription and the component is referred to as SF3/4. The main imaging purposes of SF3/4 lens are to facilitate the injection of the beam into the Main Laser near the midpoint of the TSF and, as a pair, to relay the full-power beams and pupils to the Switchyard (SY) where the beams are distributed around the target chamber.

The current baseline Main Laser design utilizes the SF3/4 lens tilted at 2.8° (various other tilt angles were explored during the Main Laser design refinement). In order to correct the lower order asymmetrical aberration introduced by the tilted spatial filter lens, the airside surface is aspherical—a bilaterally symmetric asphere (BSA). This design form was developed on the NIF prototype laser, Beamlet. The functional form of the BSA sag is given in Equation 1.

$$z=P_3x^2 + P_5y^2 + P_8(x)(x^2 + y^2) + P_{10}(x^2 + y^2)^2 \tag{1}$$

P_3 and P_5 control astigmatism, P_8 controls coma, and P_{10} controls the spherical aberration. SF3/4 is tilted in the XZ plane.

The best-fit sphere for the BSA surface is determined by differencing the BSA surface sag against the surface sag of a spherical surface. The correct radius of the sphere is determined when there are no areas in the sag difference surface map that has the spherical surface sag "below" that of the BSA (a condition that would require "adding" glass to the element instead of removing glass). Both surfaces (best-fit and BSA) have a common "vertex" of definition, i.e., the best-fit sphere determination does not tilt or decenter the sphere surface definition to obtain the "least glass removal" best-fit sphere. The last portions of the BSA surface difference that requires the radius selected as the best-fit sphere are the vertex and a section along the "X" axis. This occurs because of the "X" linear bias in the definition of the BSA surface. This effect can be seen in the sag-difference plots found in Figure 7. The maximum sag delta is defined as the greatest magnitude of the aspheric surface sag below the best-fit spherical surface. The maximum sag difference is 7.8 microns for the 2.8°-tilt design. These surface shapes and the resulting transmitted wavefronts were checked on more than one lens-design software package to verify the design.

Other aspects of the SF3/4 are as follows. SF3 needs to be displaced along the "X" axis to establish the required ±17.5 mm separation of TSF Pinholes 1 and 4 (a displacement of +1.170 mm for the 2.8° design). The SF4 is centered on the beam for Pass 4 in the TSF needing it to be +24.47 mm away from the TSF vacuum vessel axis for the 2.8°-tilt design. The injection angle needed to satisfy the pointing and centering required is 0.0222 mrad for the 2.8°-tilt design. The XZ angle coming out the SF4 is 0.01106° for the 2.8°-tilt design.

However, in the end, the mitigation of the ghost situation at SF3 or SF4 is what determines the need for the 2.8° tilt. Prescription details of SF3/4 are found in Table 4. The nominal Main Laser wavefront error and point spread function are illustrated in Figures 8a and 8b, respectively.

- Size
  - 438 x 434 x 46 mm
- Optical clear aperture
  - 410 x 406 mm
- Mechanical hard aperture
  - 413 x 409 mm
- Shape & radii
  - nearly equiconvex w/ an asphere 27,109.22 mm
- Aspherical $\{z=P_3x^2 + P_5y^2 + P_8(x)(x^2 + y^2) + P_{10}(x^2 + y^2)^2\}$
  - Air-side bilaterally symmetric asphere
  - $P_3=1.84632\times10^{-5}$ mm^{-1}; $P_5=1.85515\times10^{-5}$ mm^{-1};
  - $P_8=-8.0200\times10^{-11}$ mm^{-2}; $P_{10}=-3.43844\times10^{-14}$ mm^{-3}
  - Best-fit spherical sag departure: 0.0078 mm
  - Best-fit radius of curvature: 27,109.22 mm
- Material
  - Silica
- Back focal length (vacuum @ 1.053µm)
  - 30,000 mm
- Field-of-view usage & RMS wavefront error exiting to FL
  - 0.0334° & 0.001 wave—diffraction limited
- Nominal orientation w.r.t. mechanical axis
  - XZ tilt: 2.8°
  - XZ decenter: SF3 = +1.17 mm & SF4 = +24.47 mm

Table 4 SF3 & SF4 Details

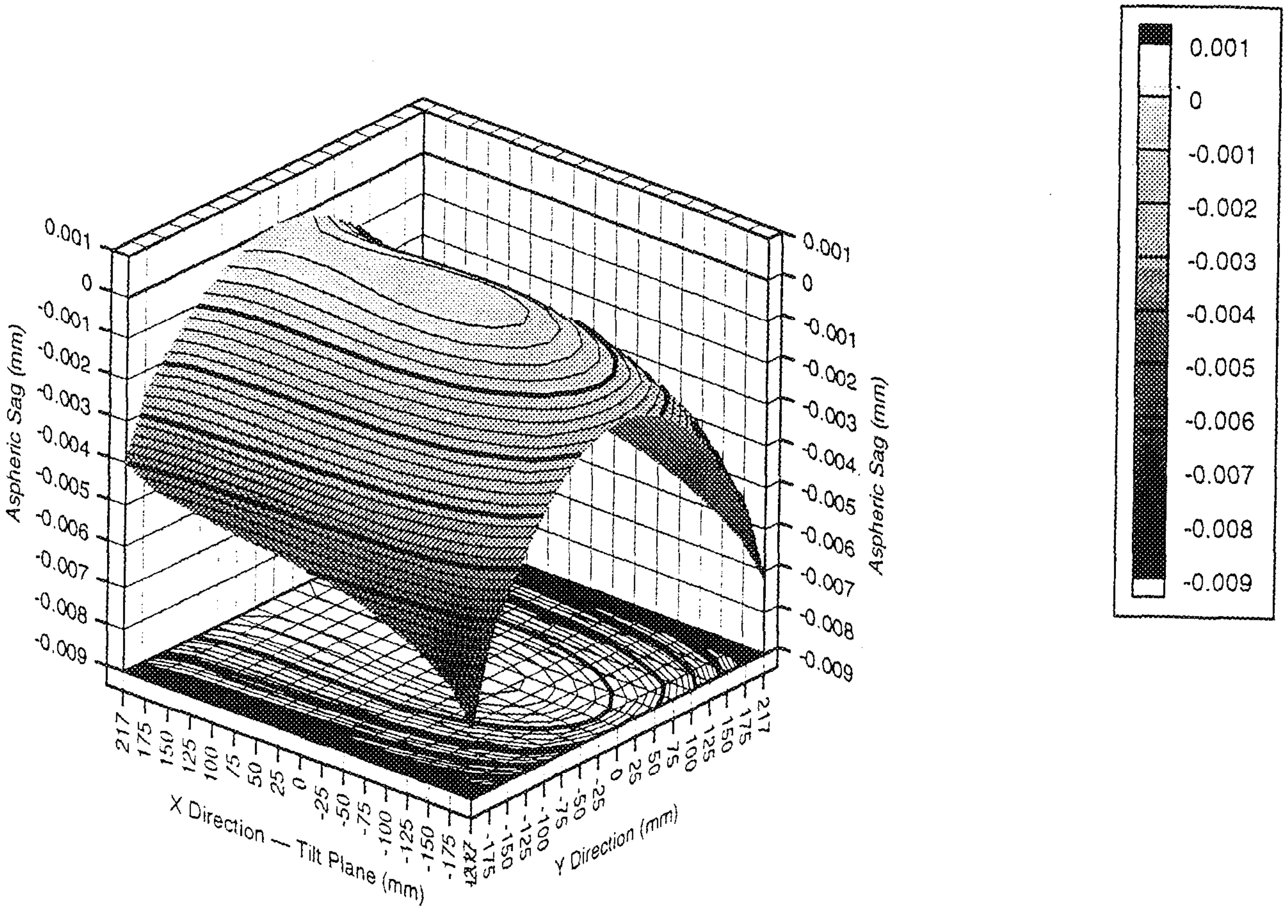


Figure 7 Glass removal amount from flat reference to obtain the desire bilaterally symmetric asphere

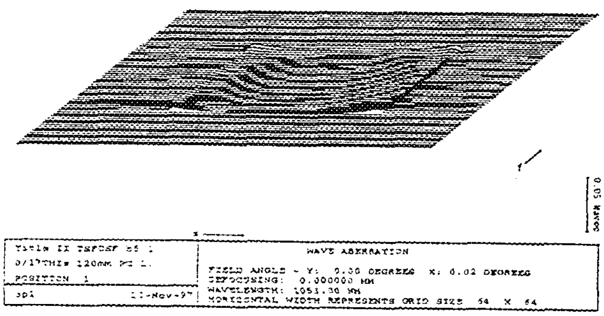


Figure 8a Wavefront error exiting Main Laser

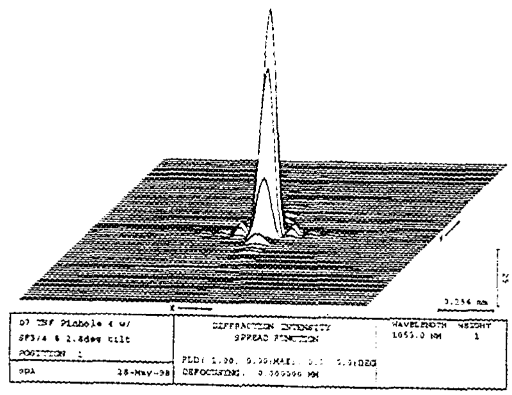


Figure 8b Point spread function at TSF Pass 4

4. TESTING AND IMPLEMENTATION CONSIDERATIONS

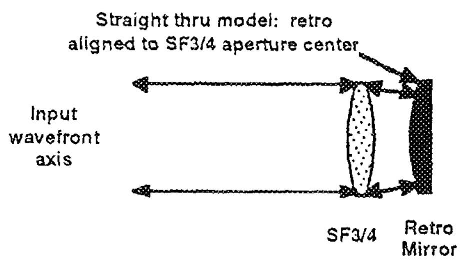
The detailed element drawings for the NIF optics are nearly complete. The design of some subassemblies is complete and have been sent out for fabrication of prototype units. Prototyping adds assurance that technologies and techniques will deliver the desired result when a beamline is put online. Some aspects of the large optics for the Main Laser SF lenses are discussed next.

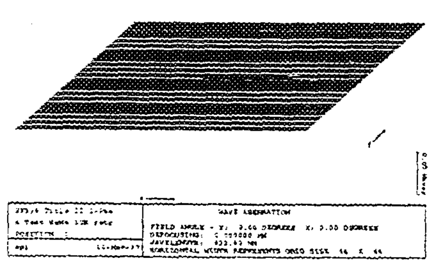
Testing

There are many things to consider in testing optical components. Some typical considerations for large optics besides instrument precision and test accuracy are simple items like air pressure, temperature, and humidity. The functional wavefront testing of the SF lenses pose additional problems. Since large-aperture interferometers that operate at 1.053 µm wavelength are not off-the-shelf items, LLNL has decided to test the SF lenses with a visible wavelength interferometer (0.667 µm wavelength). The shift in wavelength and the total immersion in air (a vacuum interface is not part of the test) induces a small, but acceptable, amount of surface change for SF1/2 from nominal due to spherochromatism. And, of course, the focal length change is also taken into account.

However, the testing of SF3/4 is not as simple or forgiving. The wavelength shift to the test wavelength changes the single pass wavefront spherical aberration along with the coma and astigmatism. Also, the lens has to be mounted in a tilted configuration similar to the in-use tilt. A double-pass test through the component can introduce a return beam slightly sheared and inclined with respect to the reference beam if care is not taken in the setup. The element under test also has to be inserted into the fixture properly so that the appropriate surface faces the interferometer as called out in the standalone test model (the same applies to SF1/2) in order to obtain the appropriate surface prescription. Getting a near null can nearly always be accomplished given enough time; however, getting the surface shape and the element desired for SF3/4 will require care and adherence to an establish test procedure.

Several double-pass test configuration have been evaluated for SF3/4 to date (Figure 9). The nominal test surface generated from the test configurations have been evaluated in the full software model of the the Main Laser to determine the effect on the performance of the laser even if the element is made otherwise perfectly, but slightly different from the nominal design, because of test configuration being only a near null (Figure 10a and 10b). The final test procedure and standalone test models are currently being developed. In order to mitigate the residuals of the near null situation, the current test plan is to use a software null based on Zernike coefficients of the wavefront from test models developed on lens design software.





EVALUATED SF3/4 TEST METHODS W/ ZERNIKE WAVEFRONT DECOMPOSITION (11/10/97)

spot impact (exceptions)	Coeff #	2.8° 2-pass tracked [illegible] Value	2.8° 2-pass tracked HeNe [illegible] Value	2.8° 2-pass straight HeNe retro [illegible] Value
piston	1	0.0017	0.0025	0
tilt, (wfr about y axis) x bias	2	0.0047	0.0419	-0.0001
tilt (wfr about x axis) y bias	3	0	0	0
focus	4	-0.0023	-0.0037	0
astigmatism, y & x line foci	5	-0.0138	-0.0228	0.0002
astigmatism, ±45° line foci	6	0	0	0
coma, x direction bias	7	0.0024	0.0211	0.0001
coma, y direction bias	8	0	0	0
spherical, 3rd order	9	-0.0045	-0.0062	0
ell. coma, x direction bias	10	-0.0002	-0.0003	-0.0004
ell. coma, y direction bias	11	0	0	0
oblique spherical, x direction bias	12	0.0001	0.0002	0.0002
oblique spherical, y direction bias	13	0	0	0
coma, 5th, x direction bias	14	0	0.0001	0.0001
coma, 5th, y direction bias	15	0	0	0
spherical 5th order	16	0	0	0
RMS of polynomial *		0.0066	0.0244	0.0002
(tilt removed		0.0062	0.0124	0.0002
RMS fit error *		0	0	0
Wavefront P-V *		0.020	0.076	0.001
Values in waves @ wavelengths (µm)		1.053	0.6328	0.6328

NOTE: • RMS of polynomial is based on a circular aperture that inscribes the respective aperture of the system analyzed

Figure 9 A test evaluation

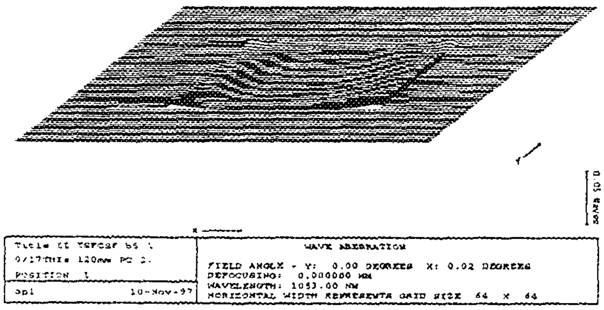


Figure 10a Main Laser wavefront, as designed

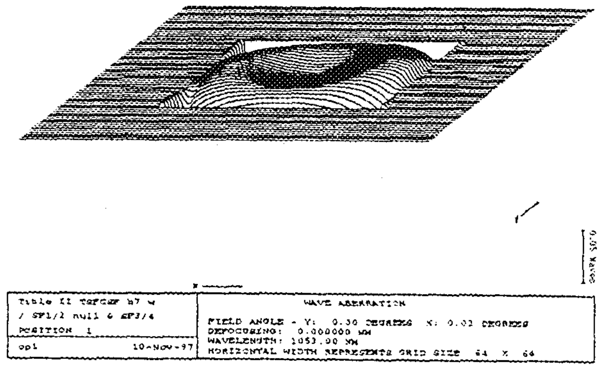


Figure 10b Main Laser wavefront, after compromising null

Acceptance Testing

Some commercial optical systems can be built to print with no component or system testing. The precision NIF optics will require components to be individually tested. The Main Laser SF lenses have standalone wavefront and back focal length callouts, so the lenses will be tested, characterized, and documented by the vendor. Besides the testing at the vendor, spot checks of the components will also be done at LLNL upon delivery of the Main Laser SF lenses. A specific SF test procedure is being developed for on-site validation. Similar procedures will be used for other major optical components.

Implementation

As with any optical system that goes to hardware, there are precautions that need to be taken in assembling the components so that the anticipated performance is achieved. The Main Laser has many components, but from the wavefront point of view the SF lens installation is of most importance. Installing an equiconvex lens is typically not a problem. For the SF lenses there is a front and a back because of the aspherical surface. Installing the SF1/2 lenses reversed front to back does not impact the performance significantly, but it would be costly during a surface reworking cycle if it's not the spherical surface that needs to be reconditioned. Also, installing the slightly rectangular components with the appropriate clocking is not a problem with SF1/2; however, SF3/4 has a biased surface shape and, therefore, must be placed in its housing with the correct clocking orientation. Figure 11 illustrates the correct clocking for SF3/4.

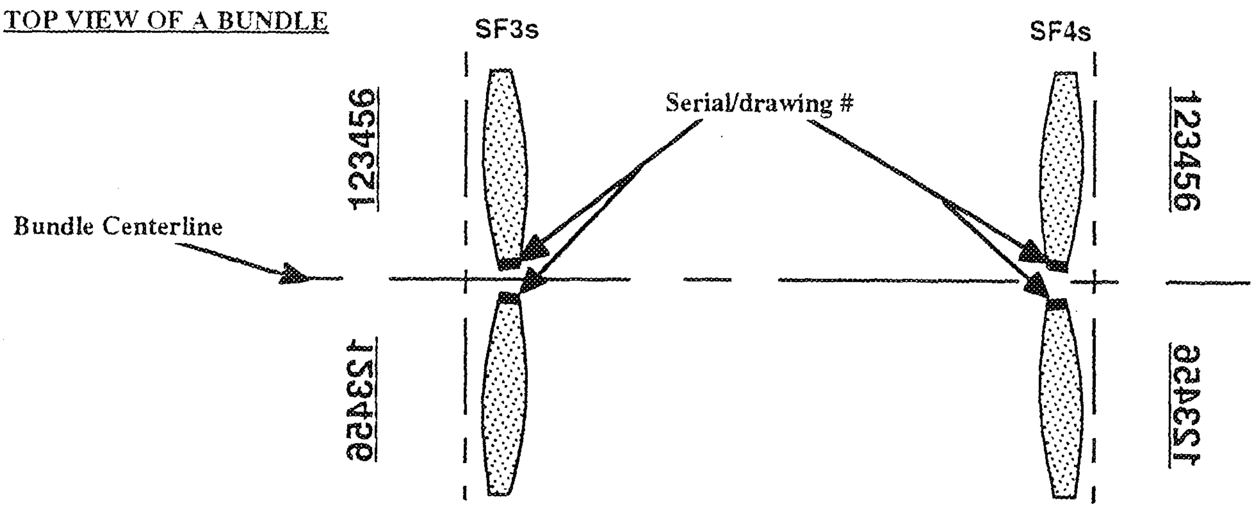


Figure 11 Correct "clocking" of SF3 and SF4 lenses on installation

5. SUMMARY AND CONCLUSIONS

The NIF project is currently in the final design phase (Title II), which will conclude in the fall of 1998. The design of major portions of the laser is complete. Select subassemblies are being prototyped to verify the designs and the technologies needed to implement them. The Main Laser SF lens designs have been successfully completed with all the functions and optical requirements being met. An initial set of the SF1/2 elements are currently being fabricated. Modeling of the test setup for SF3/4 is just now being completed. The fabrication of the initial set of SF3/4 lenses will take place early next year. The implementation phase (Title III) is earmarked to start next fiscal year. The plan is to begin operation of one bundle (eight beams) in fiscal year 2001, with NIF project completion by the end of fiscal year 2003.

6. ACKNOWLEDGEMENTS

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