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The Design of Precision Mounts for Optimizing the Conversion Efficiency of KDP Crystals for the National Ignition Facility*

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1. Introduction

A key design challenge for the National Ignition Facility (NIF), being constructed at Lawrence Livermore National Laboratory (LLNL), [Hibbard, R L , 1998], is the frequency converter consisting of two KDP crystals and a focusing lens Frequency conversion is a critical performance factor for NIF and the optical mount design for this plays a key role in meeting design specifications The frequency converter, Figure 1, is a monolithic cell that mounts the optics and is the point on the beamline where the frequency conversion crystals are optimally aligned and the cell is focused on target The lasing medium is neodymium in phosphate glass with a fundamental frequency (1ω) of 1 053 µm Sum frequency generation in a pair of conversion crystals (KDP/KD*P) produces 1 8 MJ of the third harmonic light (3ω or λ=0 35 µm). The phase-matching scheme on NIF is type I second harmonic generation followed by type II sum-frequency-mixing of the residual fundamental and the second harmonic light This laser unlike previous laser system designs, must achieve high conversion efficiency, 85%, which is close to the 90 8% theoretical maximum As a result, this design is very sensitive to angular variations in beam propagation and in the crystal axes orientation. Factors that influence the phase matching angle include crystal inhomogeneity, residual and induced stress in the crystals, the crystals' natural and mounted surface figure, mounting imperfections and gravity sag These angular variations need to be controlled within a 40 µrad error budget. The optical mount contributions to the angular error budget are 20 µrad and are what make the frequency converter in the Final Optics Cell (FOC) such a challenging precision design.

The premise of using full edge support in the FOC design is primarily driven by the spherical target chamber design that has optics mounted at multiple longitudinal angles and thus gravity sag in the crystals that needs to be minimized To meet the angular performance requirements, a precision monolithic cell with full edge support for mounting the optics to 10 µrad angular and 1-5 µm flatness tolerances is required The NIF frequency converter design is a major step in improving both conversion efficiency and precision of the mount design

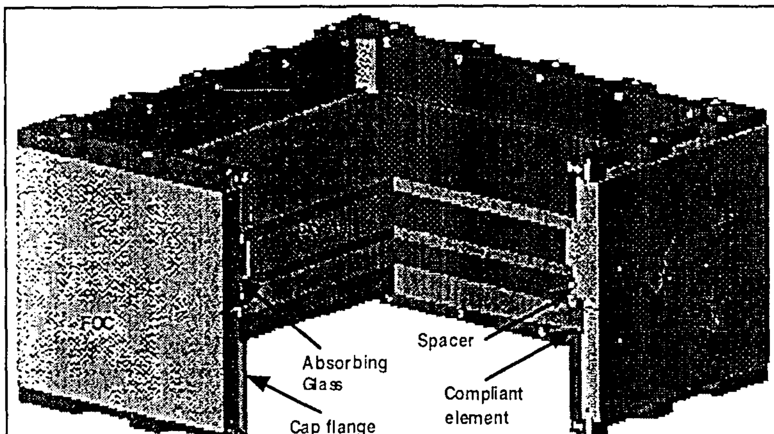


Figure 1 The Final Optics Cell, containing the two KDP crystals and the final focusing lens, all optics are mounted with full edge supports against precision machined lands, 4 µm flat

Another major consideration in the FOC design is the trade-off between cost of manufacturing the cell and the performance of the mount An interesting balance of what can be accomplished with a conventional machine tool in a commercial shop to produce prototype FOC's will be discussed Metrology issues involved in qualifying the FOC are also discussed

2.0 Design Requirements

The design requirements for the NIF final optics fall into two categories the overall system level requirements, and the driving requirement to optimize the frequency conversion efficiency Both requirements will be discussed, however the main focus of this paper will be on the mount design specifics affecting conversion efficiency Figure 2 shows the Final Optics Assembly (FOA), which houses the FOC and its actuation system The upper portion of the FOA, consists of four integrated optics modules that provide a clean barrier from the target chamber to the Class 100 final optics environment. Table 1 and Fig 2 show the stringent system alignment and motion tolerances, and cleanliness requirements to optimize the optics performance

The angular error budget, 40 µrad internal angle, for frequency conversion efficiency includes index inhomogeneity of the crystals, alignment, mount induced stresses, gravity sag, surface figure distortions, and metrology, [Wegner, P J , et. al , 1998] 20 µrad is allocated to the combined mounting affects. Other design requirements are derived requirements such as a 3 point kinematic support to tie the FOC to the actuation system to minimize the stresses induced to the cell to under 50 psi and distortions to the mounting lands of less than 0 5 µm

Table 1. System requirements for the FOC

Requirement	Specification	Reason
Crystal and lens mounting surface figure	3-5 µm	Frequency conversion (FC) efficiency
Angle between crystals and the lens	± 10 µrad	FC and alignment
Dynamic stability for final alignment	± 3 1 µm lateral and ±4 6 µm angular	Alignment
Cleanliness	Class 100	Protection from optics damage
Vacuum	1.0e-5 torr	Experiment requirement
Temperature	± 0 1 C°	FC is sensitive to temp. change
Angular resolution/acc.	± 2 µrad and ± 5 µrad	Alignment and FC
Linear resolution/acc.	± 0.1 mm & ± 0.3 mm	For focusing on target

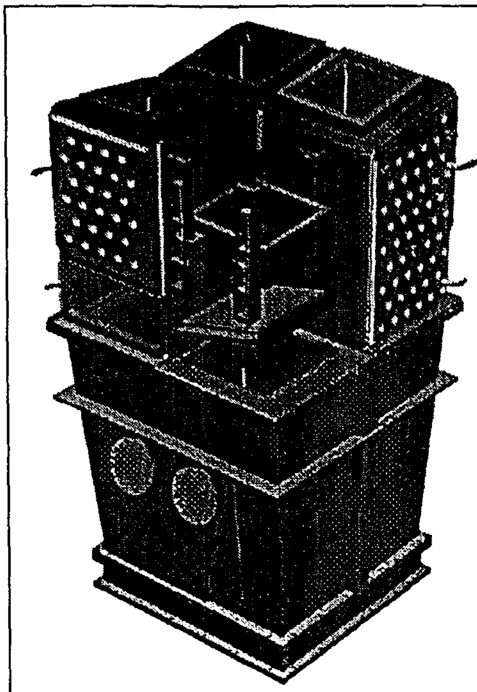


Figure 2 The Final Optics Assembly attaches to the target chamber and houses four integrated optics modules which contain the actuation system and kinematically support the FOC

3. The FOC Design

The FOC design philosophy is to passively build in all the required mount performance requirements This ensures long-term efficiencies in assembly, alignment, assembly, operations and maintenance. Then a cell needs only to be assembled correctly and checked; there is no need or possibility to adjust the figure of the three individual optics components inside the cell This also allows a much simpler design which lowers the cell cost If one considers trying to individually adjust the optics positions, surface figure and angular tolerances on 192 beam lines during operations this passive cell design becomes very attractive The philosophy is if all requirements are built into the cell the problem reduces to a manufacturing issue for the cell The target cost for manufacturing the cells (quantity 192) was set at $7,000 per cell Prototype results have validated this number

Figure 1 shows that the crystals are mounted against a precision machined surface, and on the other side is a compliant element The load is set by the shim size between the cap flange and the top of the cell, the spacing is individually calculated for each set of mating parts The absorbing glass around all the edges of the crystals is NG4 glass to absorb the SRS light from the crystals The cell is kinematically mounted to a set of three vees oriented at 120° spacing around the cell This mount design minimizes the stresses and displacements transferred to the cell, in the worst case the distortions to the cell are in the sub micron range This design will be optimized further Preliminary finite element analysis shows the cell natural frequencies are above 125 Hz

4. Prototyping Results

Prototype results discussed here will include the manufacturing of the FOC's, off-line metrology to qualify as mounted crystals and performance results from Beamlet a prototype beam of the NIF laser

Manufacturing - The FOC development effort was focused on conventional CNC machines for cost reasons The mandate for producing the first FOC's was on a best effort basis, under 10 µm flat and parallel with the goal of 3-7 µm flatness. The plan was to do the best we could with the standard commercial equipment and with a LLNL precision machinist helping in characterizing the machine and providing input into the manufacturing methodology

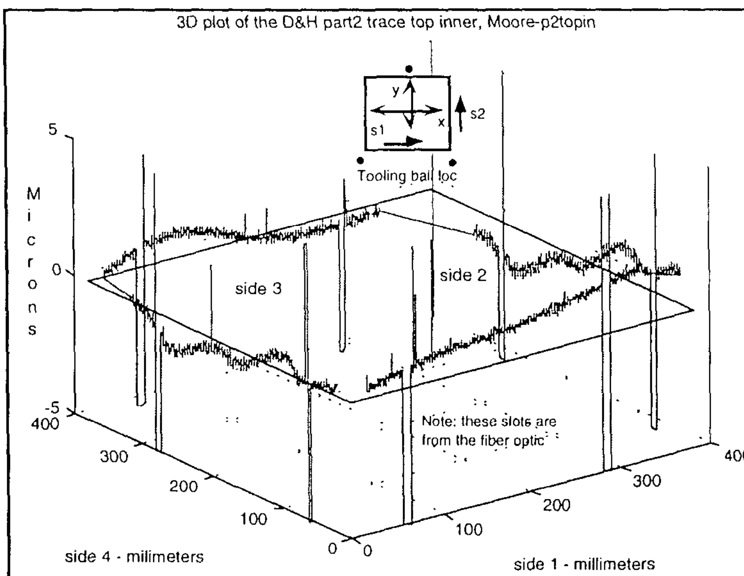


Figure 3 A 3-D display of the measured surface figure on the 37 cm prototype FOC

Figure 3 shows a 3-D plot of a measurement of the top flange made at LLNL on a Moore M5 measuring machine with an accuracy of +/- 0.25 µm, using an air bearing LVDT This figure shows the part measures flat within 4.25 µm which is an outstanding result considering the environment the machine tool is in The significant result is the machined surface is very close to the machine geometry which is the best that could be expected. A significant development hurdle has been crossed FOC's can be machined to the probable required tolerances of 3-5 µm, and can be done cost effectively at a commercial vendor

<u>Crystal as mounted performance results</u> - After a crystal is mounted, the key measurements are surface figure deformations and induced stress effects. Presently, interferometry, both transmitted wave front (TWF) and reflected wave front, (RWF) measurements, are being used. The TWF combined with frequency conversion modeling gives information about induced stress effects and RWF gives a measure of the crystal surface figure deformations and edge flaws in mounting the optic Results from mounting one doubling crystal are discussed.

Figure 4 shows a plot of the difference between TWF measurements on a 37 cm doubler in the FOC, taken on the ordinary and extraordinary axes. This plot shows crystal bulk property losses in transmission and gives a measure of the changes in $\delta n = \delta n_o - \delta n_e$, the index of refraction, assuming constant crystal thickness. Looking at the botton left corner shows a region with a bow-tie like feature, to the right is a large triangluar region, and in the upper right corner a crescent shaped feature All of these are due to internal growth imperfections within the crystal The change in the index of refraction is related to stress effects, both induced and from growth and when combined with frequency conversion modeling allows one to predict the stress effect on conversion efficiency

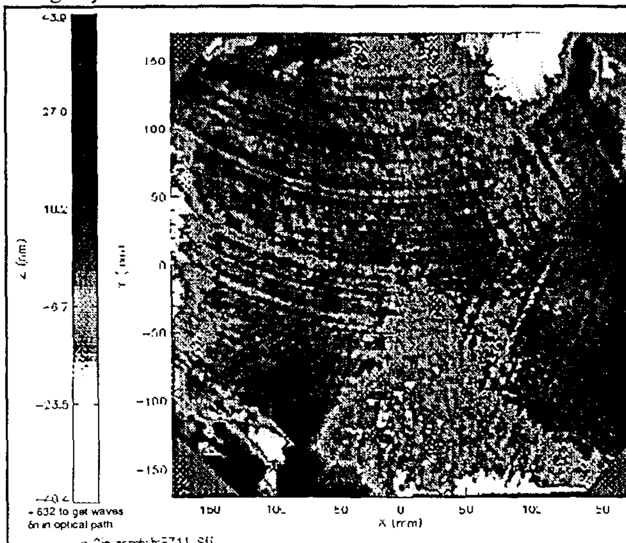
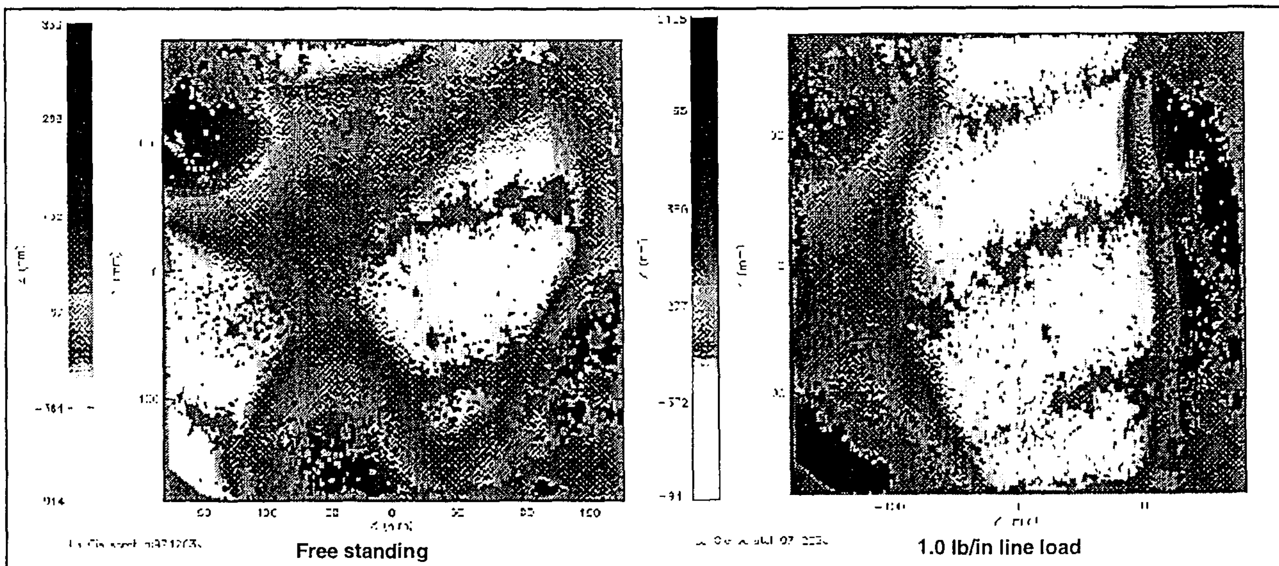


Figure 4 shows a difference plot of the ordinary minus extrodinary axes transmission paths The nm scale is converted to wave by dividing by 632

Figure 5 (a and b) show RWF measurements made on the same crystal in the FOC with a 1 0 lb/in line load and with the cap flange loosened all the way, which approximates a free-standing measure Figure 5 (a) shows the free-standing wavefront The surface figure is 2 75 µm and has a general saddle shape Figure 5 (b) shows the crystal with a 1 0 lb/in line load The overall surface figure is 3 2 µm, but the dominant shape has changed from a saddle to a more cylindrical shape where the bottom left and upper right corners have bent up. This implies the mounting is not altering the surface figure on a gross scale, but the changes in surface figure do cause local phase matching angles errors Although the surface figure affects are small this does not imply induced stress in not an issue Experiments are presently being conducted to identify the physical distortion mechanism taking place



Figures 5 (a and b) show the RWF measurements in both the loaded and free-standing conditions The free-standing is a saddle shape and the loaded becomes cylindrical.

A non-linear finite element analysis (FEA) model has been built to start modeling and predicting the details of the contact interface between the mount surface, the crystal and the compliant element Correlation of the FEA results with interfoerometry, frequency conversion modeling and Beamlet results is beginning Preliminary results indicate that with a 0-1.0 lb/in line load the crystal is starting to deform and take the shape of the FOC mount These results will be discussed

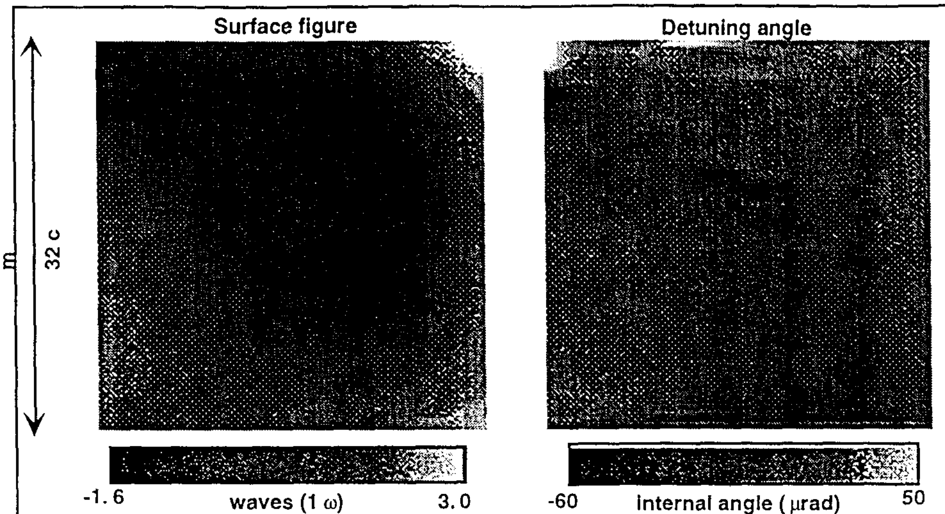


Figure 6 (a and b) show the surface figure and the detuning angle of the crystal over a 32 cm square central region in the crystal as measured on Beamlet

The FOC is installed on Beamlet and frequency conversion measurements are being done to verify results from both off-line metrology and frequency conversion The surface figure was measured on-line with a full aperture interferometer The measured figure of 5 μm peak to valley over a 32 cm central region, proved consistent with measurements taken prior to installation and is a spherical shape, Figure 6 (a) Note, this is not the full 37 cm crystal figure as a 2 5 cm band around the crystal is not measured here. Calculating the slope of the surface figure in the sensitive vertical direction and dividing by the refractive index yields the map of the detuning caused by surface refraction shown in Figure 6 (b) This shows the double detuning inferred from the surface figure has only 5% of the beam area outside of a ±22 μrad angle This figure shows that the poor conversion along the upper edge of the beam in those figures is most likely due to detuning from surface refraction These figures combined with near field irradience measurements indicate that the effects of mounting and figure and internal stress and inhomogenieties are of approximately equal importance in explaining the phase match irregularities observed in this crystal

Summary

The FOC mount design critically affects the optical performance of the frequency conversion crystals Preliminary results show influences of the line loads, surface figure, induced stresses on frequency conversion The design and analysis is proceeding with detailed tests to understand the magnitudes and relations between these effects The monolithic FOC cell design has many advantages in its simplicity and how it passively builds in all the desired accuracy for mounting the optics Manufacturability has been proven at a level of 3-5 μm of surface figure Further work is needed to finalized the specifications on the required flatness and performance of the mount

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References

Barker , C E , Auerbach J M , Adams, C A , Bumpas, S E., Hibbard, R L , Lee, C L , Campbell, J H , Wegner, P J , Van Wontergham, B M , and Caird, J. A , "National Ignition Facility Frequency Converter Development", 2nd Annual International Conferenece on SOlid-State Lasers to Inertial Confinement Fussion, Paris France, 1996

Hibbard, R. L , English , R E. Jr., De Yoreo, J J , and Montesanti, R C , "Frequency Converter Design and Manufacturing Considerations for the National Ignition Facility", OSA Optical Fabrication and Testing, Summer Topical Meeting, 1998

Wegner, P J , Auerbach J. M , Burkhart, S C , Couture, S. A , De Yoreo, J J , Hibbard, R. L , Norton, M A , Whitman, P A , Hackel, L A , "Frequency Converter Development for the National Ignition Facility(*)", Solid State Lasers for Application (SSLA) to Inertial Cxonfinement Fussion (ICF) 3rd Annual Inetrnational Cnference, Moterey Califirnia, USA, 1998

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