Beamlet Focal Plane Diagnostic

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Beamlet Focal Plane Diagnostic^{*}

by

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Abstract

This paper describes the major optical and mechanical design features of the Beamlet Focal Plane Diagnostic system as well as measurements of the system performance, and typical data obtained to date. We also discuss the NIF requirements on the focal spot that we are interested in measuring, and some of our plans for future work using this system.

1. Introduction

The Beamlet laser is a single-beam prototype for the 192 beam National Ignition Facility (NIF) laser system¹. In the past year we installed and activated a large vacuum vessel (55 m³) and an associated optical diagnostic system at the output of Beamlet to characterize the laser irradiance at the primary focal plane of the target. The system is also designed to test prototypes of the final focusing optical system, including the frequency converters, lens and diffractive optics used to produce the desired irradiance distribution at the focal plane. A similar system is planned for deployment in the National Ignition Facility itself to test the performance of selected beamlines.

2. System Requirements

One of the principal system design requirements for the Beamlet Focal Plane Diagnostic (FPD) is to propagate the full beam energy through a prototype final optics assembly to the primary target plane. The final optics assembly includes KDP/KD*P frequency conversion crystals, a final focus lens, and diffractive optical elements. One of the diffractive optics is a kinoform phase plate² (KPP) which introduces a fixed pattern of phase deviations on the incident wavefront in order to tailor the intensity profile of the far field focal spot. A consequence of using a KPP is that near field intensity modulation develops rapidly downstream. Since the final optics are designed to operate near the damage threshold of fused silica optics the additional near field modulation would damage any beam sampling optics inserted before the primary focal plane. We decided, therefore, to allow the beam to expand beyond the final focus until peak fluences were lower than those seen prior to final focus. Beam propagation models indicated that a three-fold increase in beam area should allow the primary beam sampling optics to function without optical damage at the highest output fluence.

The most stringent NIF requirement for the far field spot on target is ≥ 10 times the diffraction limit of the final focus optics at a wavelength of 0.35 μm . To ensure that our diagnostics could measure the spot with sufficient accuracy, we required the diagnostic imaging optics to achieve ~ 2 times diffraction limited performance in the near ultraviolet.

Non-linear self-focusing in the final optics can cause beam filamentation and consequential optical damage. Intensity and/or phase ripples with near field spatial scale lengths as small as 100 μm were considered to be a significant threat. We required our high resolution near field diagnostic, therefore, to resolve features < 100 microns in size at the input optics.

Additional requirements included optical energy measurements with $\leq 3\%$ accuracy at 1ω , 2ω and 3ω , and temporal pulseshape measurements with 200 ps resolution. Laser assisted alignment of the diagnostics was required at 1ω , 2ω and 3ω .

3. System Design

An off-axis Cassegrain telescope was chosen to sample and image the beam. The basic design shown in Figure 1 was chosen to provide an unobstructed aperture, while allowing the beam to be sampled and attenuated by bare surface Fresnel reflections from each of the mirrors. The primary mirror, M_1 , had to be 1 meter in diameter to allow sufficient beam expansion to avoid optical damage. The centers of curvature of M_1 and M_2 were chosen to coincide so that a Focault knife edge test at their common center would verify their figure and alignment simultaneously.

1. The Focal Plane Diagnostic (FPD) post-focus telescope is an off-axis Cassegrain.

The full system, including a prototype final optics assembly, telescope, beam dumps, and optical diagnostic tables is shown in Figure 2. In this configuration a wedged lens provides the input vacuum barrier as well as refractive color separation at the primary focal plane. The primary vacuum vessel (2.2 m dia. x 12 m long) houses the Cassegrain telescope and other beam sampling optics. Absorbing glass in the primary beam dump is oriented so that the Fresnel reflection from its front surface is captured by a secondary beam dump. A 30 cm diameter calorimeter located behind the secondary mirror, M_2 , provides the primary energy measurement reference for other optical diagnostics on Tables 1, 2 and 3. A photograph of the outside of the vacuum vessels looking from the final focus optics toward the telescope vacuum vessel is shown in Figure 3.

2. The FPD vacuum vessels are shown with the original prototype final optics assembly.

3. The FPD hardware looking from the final optics assembly toward the post-focus telescope vacuum vessel.

Calibration of energy sensors on the diagnostic tables was performed by passing only 1 color at a time through a pinhole at the primary focal plane, as shown in Figure 4. The beam dump for other colors in Figure 4 was described in more detail in another paper given at this conference³.

Energy and power diagnostics were provided on FPD Table 1 as shown schematically in Figure 5. Color separation results from dispersion in the wedged final focus lens. The negative lens on Table 1 merely increases the geometrical separation of the colors. CCD cameras are also provided on Table 1 for centering the 1ω beam in near field planes and pointing the 1ω beam to the desired far field location.

One half of Table 2 provides 3ω far field and a low resolution near field measurement capability, as shown in Figure 6. A far field aperture stop can be inserted at the 3ω focal

plane so that the field of view of the energy sensor is appropriately restricted. Typically we set the aperture stop equal in size to the laser entrance hole (LEH) of a NIF scale 1 hohlraum. The multiple image camera obtains far field images in various planes to allow precise determination of the location of best focus.

6. One half of Table 2 provides 3ω far field and low resolution near field measurements.

The other half of Table 2 provides a higher magnification far field and near field measurement capability as shown in Figure 7. Here, we can also place an aperture stop at the far field image plane. On this table, however, we frequently install a beam block at the far field image plane and allow only scattered 3ω light into the diagnostics. The “Schlieren” images obtained in this way allow us to determine precisely the location of scattering sources, as well as the angular distribution of light scattered off-axis.

7. The other half of Table 2 provides a higher magnification far field and another near field image.

Our highest resolution near field measurement capability resides on Table 3, as shown in Figure 8. A calorimeter designed to accept wide angle scattered light (up to 3 mrad) is

also located on this table. Fast pulshape measurements (≤ 20 ps) can be performed using a LLNL streak camera.

8. Table 3 provides our highest resolution near field, a wide field-of-view calorimeter, and streak camera based temporal measurements.

4. System Performance

Near diffraction limited performance was obtained from the Cassegrain telescope as illustrated in Figure 9. The right hand side shows a far field image taken on Table 2 for a 9- μm “point” source (at 2ω) situated at the 3ω prime focal plane. In this spot, 81.5% of the power is within $\pm 2.4 \mu\text{rad}$ which is roughly 1.6 times the diffraction limit, and ensures that we are close to 2 times the diffraction limit at 3ω .

9. Near diffraction limited performance has been obtained from the FPD telescope.

Some typical far field data taken for Beamlet full system laser shots with and without a kinoform phase plate in the beam is shown in Figure 10. The circle in the images represents a 600 μm diameter spot size that is required to contain 98% of the 3ω energy on NIF. The data shows that we are very close to meeting the NIF requirement of 98% of the 3ω energy inside of a 600 μm diameter circle. Details of the 3ω spot size measurements are given in another paper at this meeting⁴.

10. Typical far field data shows that Beamlet closely approaches NIF beam quality requirements.

A USAF 1951 test target was used to measure the resolution of our high resolution near field diagnostic camera, as shown in Figure 11. The image shows that group 2, element 6 is clearly resolved at > 14 lines per mm. This corresponds to a spatial wavelength of $\sim 70 \mu\text{m}$. Despite the excellent resolution of this diagnostic we have seen no evidence of beam filamentation to date in the final optics up to 3ω powers near $5 \text{ GW}/\text{cm}^2$.

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11. The high resolution near field image of USAF 1951 test target demonstrates ability to resolve 70 micron features at the input optics.

5. Future development

In the coming year we plan to install and test new final optics configurations on Beamlet. The major change we will make involves putting the frequency conversion crystals inside the vacuum chamber as shown in Figure 12. This allows the beam to pass through the vacuum barrier window at the $1.05 \mu\text{m}$ wavelength, where the damage threshold of fused silica is substantially higher than it is at $0.35 \mu\text{m}$. Later in the year, we plan to replace the wedged final focus lens with a symmetric lens plus a color separation diffraction grating. In this way, Beamlet will become as much like the NIF baseline design as we can make it.

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Figure 12.

12. New prototype final optics configurations with frequency conversion crystals inside the vacuum chamber will be tested in the coming year.

6. Conclusion

Beamlet's new Focal Plane diagnostic system became operational in FY'96, with all of our essential diagnostic specifications being met. We have taken a wide range of data to validate several aspects of the NIF baseline design^{4,5}. Future development on Beamlet will include reconfiguration of the final optics package to allow propagation of the beam through the vacuum barrier window at 1ω , followed by frequency conversion inside the vacuum chamber.

7. References

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8. Figure Captions

1. The Focal Plane Diagnostic (FPD) post-focus telescope is an off-axis Cassegrain.
2. The FPD vacuum vessels are shown with the original prototype final optics assembly.
3. The FPD hardware looking from the final optics assembly toward the post-focus telescope vacuum vessel.
4. A stainless steel beam dump strips other colors at the primary focal plane for energy measurement calibration.
5. Table 1 diagnostics provide for alignment, energy and power measurements.
6. One half of Table 2 provides 3ω far field and low resolution near field measurements.
7. The other half of Table 2 provides a higher magnification far field and another near field image.
8. Table 3 provides our highest resolution near field, a wide field-of-view calorimeter, and streak camera based temporal measurements.
9. Near diffraction limited performance has been obtained from the FPD telescope.
10. Typical far field data shows that Beamlet closely approaches NIF beam quality requirements.
11. The high resolution near field image of USAF 1951 test target demonstrates ability to resolve 70 micron features at the input optics.
12. New prototype final optics configurations with frequency conversion crystals inside the vacuum chamber will be tested in the coming year.

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