Optical Characterization of the OMEGA Beam Profile at High Energy Using the Full-Beam-In-Tank Diagnostic

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The OMEGA Laser System performs direct-drive inertial confinement fusion implosion experiments by using 60 ultraviolet (UV) beams focused onto a target in the center of a spherical target chamber.[1] Target-physics simulations suggest that the total on-target intensity (power per unit area) nonuniformity, with all 60 beams overlapped, must be less than 1% rms for optimum performance. The laser diagnostics used to assess on-target uniformity are located upstream of the target chamber and comprise a spatially integrated energy diagnostic (the harmonic energy diagnostic) and a temporal pulse-shape diagnostic (a P510 UV streak camera), both of which provide measurements of all 60 beams on each OMEGA shot. Experiments that independently estimate the on-target uniformity using measurements of x-ray production on metal targets suggest, however, that the balance is worse than the laser diagnostics indicate.[2] There is a limited capability for measuring the fluence distributions in the far field on OMEGA—the UV equivalent target plane (UV-ETP) diagnostic.[3] The ETP measurement does not include the full-energy effects of the final optics in the system, and beam-to-beam variations in target-plane fluence distributions cannot be effectively investigated using this setup. A new diagnostic, known as the full-beam-in-tank (FBIT) diagnostic[4–6] has therefore been developed to more accurately characterize the beam-to-beam variation in target-plane fluence.

The FBIT diagnostic is capable of measuring the on-shot, on-target focal spot of multiple beams inside the OMEGA target chamber. A direct measurement of a full-energy OMEGA beam (~500 J/beam) at target chamber center (TCC) presents a significant challenge. To overcome this, a small sample (~0.9 mJ) of the full-energy beam (Fig. 1) is collected by the FBIT diagnostic in the target chamber. To obtain the attenuated beam for characterization, the vacuum window and debris shield are altered. The standard vacuum window is replaced by one with a 7.5-arcmin wedge. This uncoated optic allows the light to undergo multiple Fresnel reflections, each emerging at a slightly different angle. The fourth-order reflection (with ~0.0003% of the incident beam energy) is the one that enters the FBIT diagnostic. The debris shield, placed after the vacuum window, serves as a compensating wedge to address the aberrations introduced by the propagation of a focusing beam through the wedged vacuum window. Two

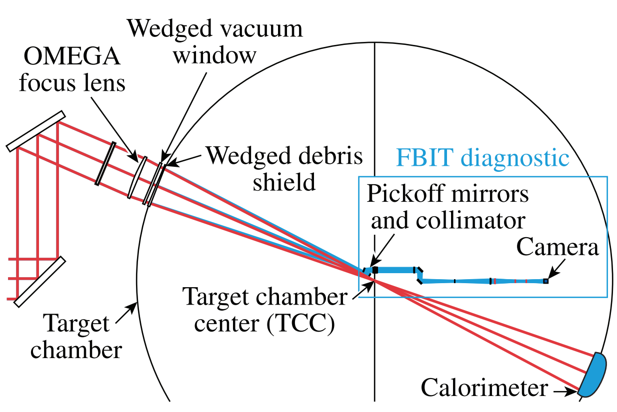

Figure 1
A schematic of the FBIT diagnostic. The main OMEGA beam is shown in red; the light blue rays indicate the fourth-order reflection from the wedged vacuum window that enters the FBIT diagnostic.

small mirrors at the front end of the FBIT diagnostic, aligned close to TCC, are designed to receive the Fresnel reflection of the main OMEGA beam for imaging onto a scientific-grade charge-coupled–device (CCD) camera, which is housed in a bubble since the target chamber is at vacuum. The remainder of the main beam propagates through TCC and is terminated at a calorimeter mounted in the opposing port, which measures the on-target energy. In addition to providing a direct measurement of a beam's fluence in the target chamber, the front end of the FBIT system rotates to characterize multiple beamlines within a single shot day.[4]

Initial experiments using the fourth-order reflection from the vacuum window had significant background light that made detailed characterization of a smoothed OMEGA focal spot difficult. Through modeling and laboratory measurements, it became clear that the source of the background light is scatter from the main beam. An upgrade was proposed for the FBIT diagnostic, referred to as FBIT 2.0, to address the background light issues. The primary design change was to utilize the second-order reflection from the wedged vacuum window, instead of the fourth-order reflection. Use of the second-order reflection increases the signal-to-background ratio since the increase in signal is much greater than the increase in background light as a result of collecting a solid angle that is in closer proximity to the main beam.

To maintain consistent intensities within FBIT for the upgrade, the first two mirrors in the diagnostic are replaced by uncoated NG-9 filter glass. There is a Fresnel reflection off of the first surface of the filter glass, and the remaining energy is absorbed by the filter. The attenuated second-order reflection from the wedged vacuum window then travels down the same path as the original FBIT diagnostic to the CCD.

Initial measurements taken with the FBIT 2.0 diagnostic indicate that the dynamic range of the smoothed far-field focal spots has been improved from the original design. Figure 2 shows an azimuthal average fit of one of the smoothed focal-spot images from the FBIT 2.0 diagnostic. The red vertical line indicates the $R_{1/e}$ point on the azimuthal average fit curve, which is 364 μm for this beam. The fitting is much improved compared to the original FBIT diagnostic.[6] The fit, as expected, trends toward zero at the tail, whereas the data do not, even though a threshold is applied to the data at 0.5%. Some residual background light present in the images is currently being investigated.

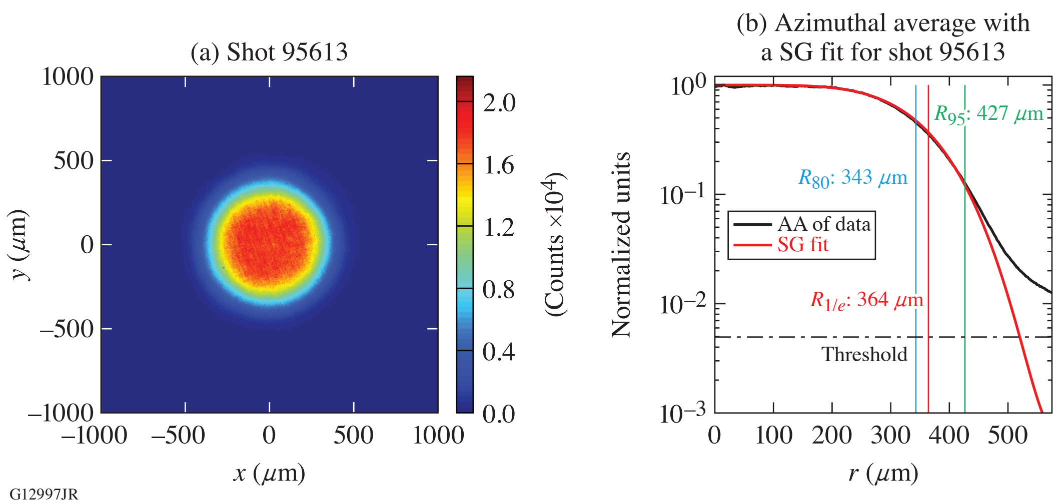

Figure 2
(a) A smoothed focal spot image taken with the FBIT 2.0 diagnostic; (b) The black curve is the azimuthal average (AA) of the smoothed focal spot data shown in (a), and the red curve is the super-Gaussian (SG) fit to the azimuthal average of the data. A threshold is applied to the image at 0.5% of maximum. The R_{80} of the AA of the data is shown by a blue vertical line; the R_{95} of the AA of the data is shown by a green vertical line.

The FBIT diagnostic was developed to measure the on-target beam-to-beam focal-spot variation on the OMEGA Laser System. With the FBIT 2.0 upgrade, signal-to-background levels were significantly increased, allowing for precise characterization of on-shot OMEGA focal spots. Further aberration correction and background light mitigation will further improve measurement fidelity as the FBIT is used to characterize up to 31 of OMEGA's 60 beams.

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