In-Tank, On-Shot Characterization of the OMEGA Laser System Focal Spot

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The success of inertial confinement fusion experiments conducted on LLE's OMEGA 60-beam laser depends on the uniform illumination of the target. For these experiments, not only is the focal-spot intensity (i.e., power/unit area) of each beam tightly controlled, but the overall on-target, beam-to-beam intensities must be carefully balanced. Simulations indicate that the root-mean-square (rms) intensity balance on target should be <1% (Ref. 1). Depending on the amount of overlap between the beams, this requirement implies that the focal-spot intensities of each of OMEGA's 60 beams must achieve an rms balance of 2% to 3%.

To meet this specification, much attention has been paid to the power balancing (i.e., energy/unit time) of each of OMEGA's 60 beams at the laser output.[2] Through a balancing of gains, losses, and frequency conversion, OMEGA now consistently delivers an rms power balance that meets the 2% to 3% specification. As stated above, however, the quantity of importance to experiments is the *on-target intensity* balance. To characterize the intensity balance, one must also measure the on-shot focal spot of each beam at the target. Up until now, OMEGA has had the ability to characterize the on-shot focal spot of four beams (one at a time) at an equivalent target plane (ETP) located upstream of the target chamber. The ETP provides a detailed analysis of a single-beam focal spot, but it cannot provide an assessment of intensity balance on target. In addition, since the ETP pickoff is upstream of the target chamber, any effects caused by nonlinearities in the final focusing optics (located on the target chamber) are not characterized.

To characterize actual on-shot conditions, LLE has built a full-beam-in-tank (FBIT) diagnostic that measures the OMEGA focal spot at the center of the target chamber (TCC). The FBIT diagnostic picks off a full-aperture, low-energy sample of the beam after it has been transmitted through most of the final optics assembly. Specifically [see Fig. 1(a)], the standard plane-parallel, antireflective (AR)-coated vacuum window is replaced with an uncoated window with a small wedge (7.5 arcmin). The 3.7% reflection from the back surface of this wedge provides a low-energy sample of the main beam. This sample beam creates a sequence of forward-going replica beams, each having an intensity that is $(0.037)^2$ times that of the previous replica.

As shown in Fig. 1(b), each of the replicas comes to a focus at a different location in the target chamber. This provides a region near the TCC, where one of the replicas can be intercepted and delivered to a camera. The OMEGA target chamber contains several ports for instruments that are used to diagnose a particular experiment. Six of these ports contain ten-inch–manipulator (TIM) platforms that provide a flexible means to insert different diagnostics into the target chamber while maintaining vacuum conditions. The FBIT diagnostic uses TIM's to insert a pickoff optic, imaging optics, and a charge-coupled–device (CCD) camera into the target chamber to capture one of the beam replicas from the wedged vacuum window.

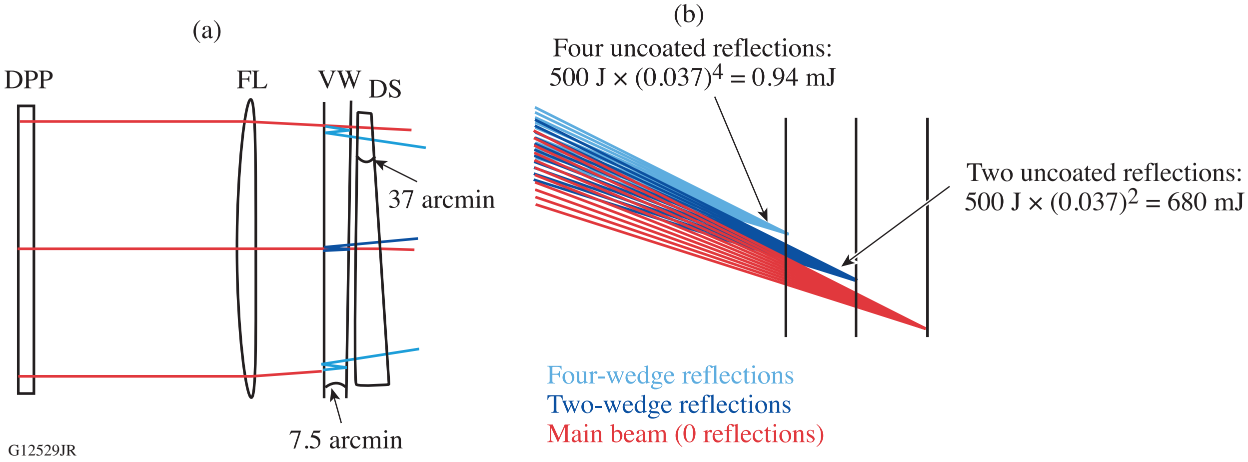

Figure 1
(a) Diagram of the final optics assembly used for the full-beam-in-tank (FBIT) diagnostic. For clarity, wedges are exaggerated and some of the reflections have been omitted. (b) The uncoated wedged vacuum window creates a series of replicas of the main beam. Each is reduced in intensity by 0.037^n, where n is the number of reflections in the wedge. Each replica focuses at a different location in the target chamber. DPP: distributive phase plate, FL: focus lens, VW: vacuum window, DS: debris shield.

One of the key requirements for any focal-spot diagnostic is that it does not introduce significant optical distortions so that the measured focal spot is an accurate representation of the actual spot. The wedged vacuum window provides an excellent method for sampling the beam near the target, but a focusing beam that makes multiple passes through a wedged optic is significantly aberrated. To mitigate this, the aberrations from the wedge are compensated by introducing an opposing wedge (37 arcmin) in the debris shield [see Fig. 1(a)]. In addition to the wavefront introduced by four passes through the wedged vacuum window, there are also manufacturing errors that will further degrade the focal-spot quality. With four reflections from the vacuum window surfaces, a high-quality reflected and transmitted wavefront is required. The achieved reflected and transmitted wavefront for the vacuum window was of the order of 0.06 waves ($\lambda = 632.8$ nm), which results in minimal additional distortion of the focal spot from manufacturing. Figure 2(a) shows a simulated focal spot for a diffraction-limited input. Included in this simulation are the measured reflected and transmitted wavefront of a manufactured wedged vacuum window and the measured transmitted wavefront of a manufactured compensating debris shield, showing that the system can be built with minimal distortion to the incoming beam (the yellow circle represents 12× the diffraction limit, which roughly corresponds to the OMEGA focal-spot size). Figure 2(b) shows an on-shot measurement of the OMEGA focal spot made by the FBIT diagnostic. The measured focal spot is significantly more aberrated than the spot predicted from just the aberrations of the FBIT itself. To ensure that the FBIT diagnostic will provide an accurate measurement of the focal spot, we have characterized each of the wedged vacuum window/debris-shield combinations. Figure 2(c) shows the predicted focal spot for a diffraction-limited input to the combination with the largest measured aberrations. While this predicts significantly more degradation to the focal-spot quality, this effect is still overwhelmed by the system aberrations [see Fig. 2(d)].

We have presented the design and implementation of an on-shot, on-target focal-spot diagnostic for the OMEGA Laser System. To our knowledge, this is the first diagnostic capable of measuring the on-shot focal spot of a large laser system inside the target chamber. The diagnostic makes use of an uncoated, wedged vacuum window to create reduced energy replicas of the main beam. One of these replicas is captured by a TIM-based instrument and relay imaged to a CCD camera. We have measured on-shot far fields and near fields and are working to characterize at least 30 beams during this fiscal year. These data will provide an estimate of the on-shot laser uniformity on target.

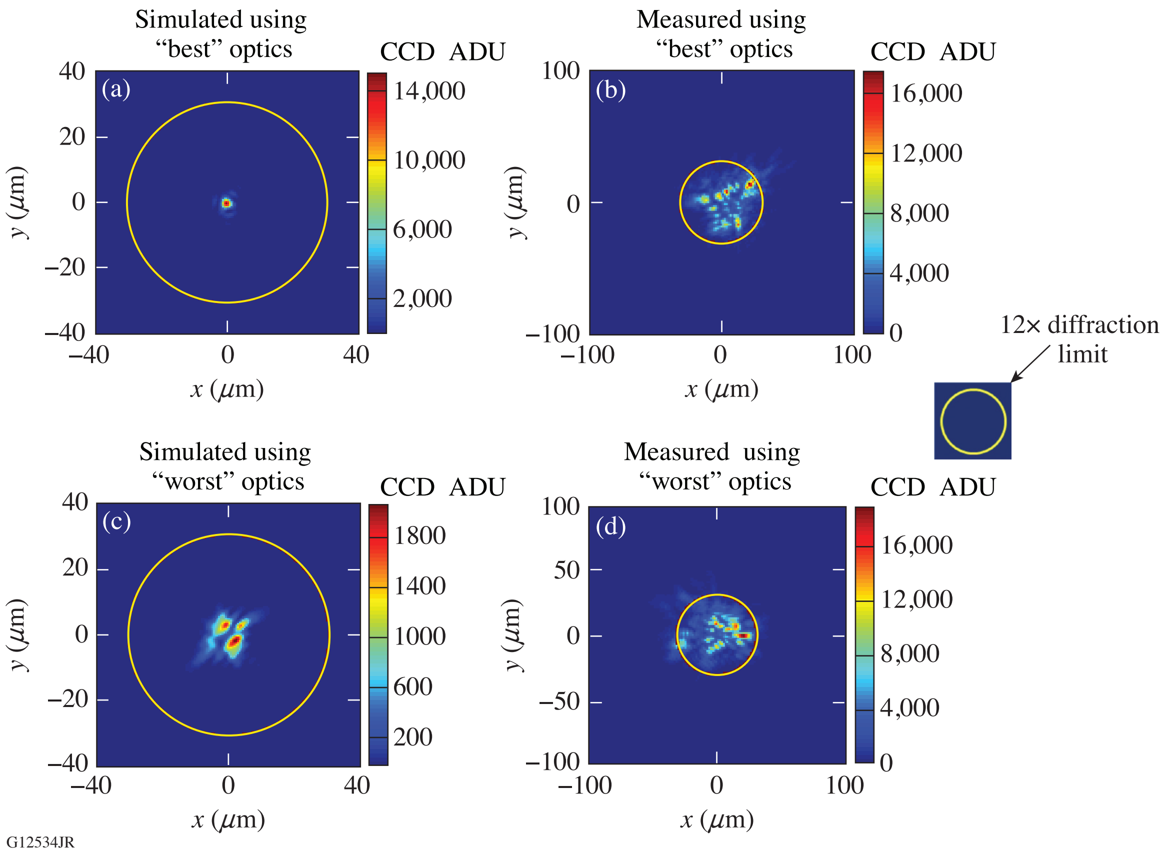

Figure 2
(a) Predicted FBIT-measured focal spot using the wedged vacuum window/wedged debris-shield combination with the "best" optical quality (using a diffraction-limited input to the final optics assembly). (b) FBIT measurement of the on-shot OMEGA focal spot using this combination of optics to generate the replica beam. (c) Predicted FBIT-measured focal spot using the wedged vacuum window/wedged debris-shield combination with the "worst" optical quality (using a diffraction-limited input to the FBIT). (d) FBIT measurement of the on-shot OMEGA focal spot using this "worst" combination of optics to generate the replica beam. The yellow circle represents a 12× diffraction-limited focal-spot size. ADU: Analog-to-digital units.

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1. V. N. Goncharov *et al*., Plasma Phys. Control. Fusion **59**, 014008 (2017).

2. S. Sampat *et al*., Appl. Opt. **57**, 9571 (2018).