Section 2
PROGRESS IN LASER FUSION

2.A Irradiation Uniformity Measurements for Six UV (351-nm) OMEGA Beams

The success of direct-drive laser fusion requires detailed knowledge and control of the illumination uniformity on a spherical target irradiated with multiple beams. Studies of this issue have been a principle part of the laser-fusion program at LLE for some time.[1-3] For 24-beam experiments with 1-ns, 1053-nm IR pulses, we have used the measured intensity distribution of the beams in the equivalent target plane (ETP) to simulate the actual target irradiation uniformity.[4] We estimate the uniformity in a similar fashion for six-beam UV illumination.

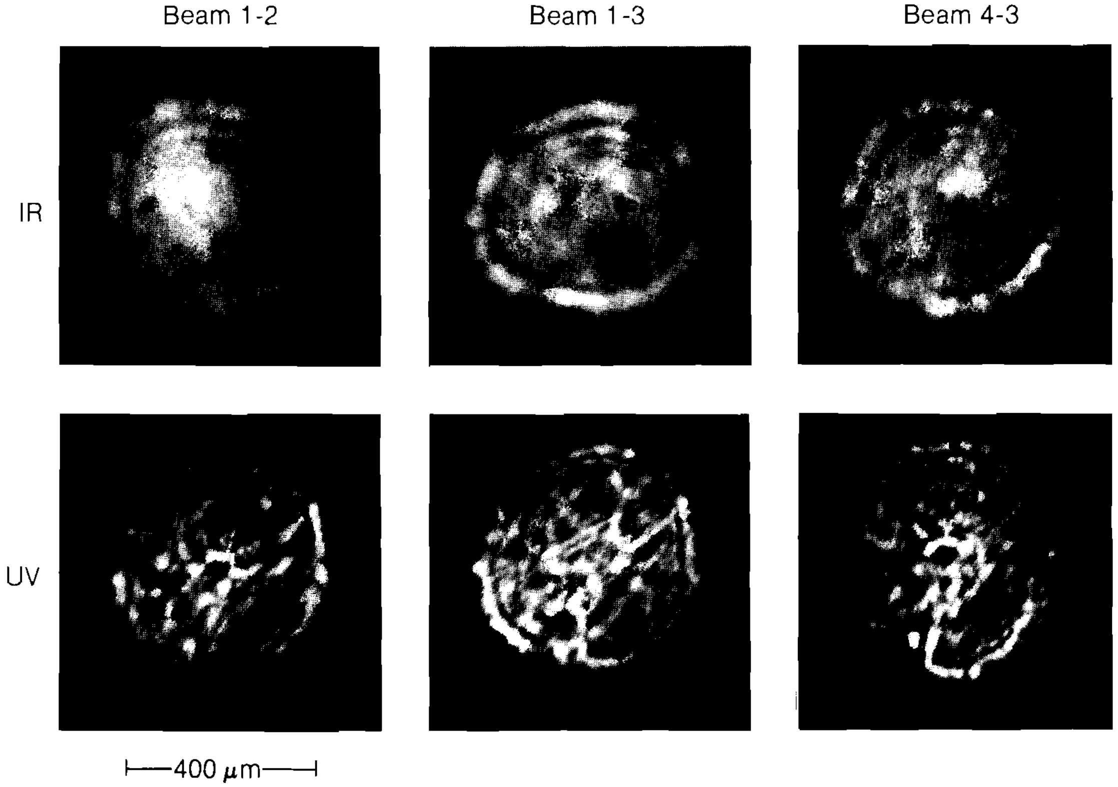
For the IR beams, we begin with ETP photographs recorded in the beam-diagnostic packages (BDP's) installed in each OMEGA beam.[5] The photographs are scanned, digitized, and intensity corrected, and an azimuthally averaged intensity profile is obtained for each beam. These profiles are inserted into a spherical beam-superposition code[3] which maps the intensity profiles onto the surface of a spherical target for specific beam geometries and focusing conditions. This superposition code also models refraction of the laser-light rays in the corona of the laser plasma and includes simplified descriptions for the laser-plasma absorption. The result is an overall estimate of the energy deposition uniformity which can be used to estimate the target-drive nonuniformity in two-dimensional (2-D) simulations of laser-fusion-target implosions.

With the conversion of the output of OMEGA from IR to UV (351 nm),[6] the assessment of the irradiation uniformity presents new problems. The nonlinear intensity dependence of the frequency conversion process[7] tends to accentuate spatial variations in the intensity profiles of the beams propagating through the conversion crystals. In addition, the crystals and following optics in the beamline can introduce phase modulation into the beam which is subsequently transformed into intensity modulation in the target plane.

Concurrent with the activation of the first six UV beams of OMEGA during the fall of 1983, an experimental program was established to measure the 2-D intensity distribution of each beam in the target plane.[8] The optical system for obtaining both IR and UV ETP photos of each of the up-converted beams of OMEGA has been described previously.[9] The energy in each beam is measured with a multi-wavelength energy-sensing system (MESS) comprised of a 20-cm aperture calorimeter and three photodiodes in conjunction with an integrating sphere.[10]

Figure 20.7 shows individual images of the ETP intensity distribution for three of the up-converted beams in both the IR and UV, recorded at an equivalent target plane located 1,600 μm inside best focus. The IR-beam image shows a clear ring structure. This structure is replicated in the UV distribution. Improvement in the front-end driver-line optics of OMEGA to be made in the fall of 1984 should markedly improve these distributions.

Fig. 20.7
Characteristic intensity distributions in the target plane for three of the six unconverted OMEGA beams. Shown are the IR and UV intensity distributions for tangential focus on the surface of a 400-μm-diameter spherical target. With the current beam output, the mean UV intensity on the surface of the target would be $\sim 5\times10^{13}$ W/cm^2.



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The ETP images are digitized on a Perkin-Elmer PDS microdensitometer, with the known intensity ratio of successive images to calibrate the film response. The resulting data array describes the image intensity as a function of position in the ETP.

Figure 20.8 shows the iso-intensity contours (12% contour intervals) of the six UV beams. These particular records were obtained for the same ETP located 1,600 μm inside best focus. They correspond to the intensity distributions in each beam on the surface of a spherical, 215-μm-radius target when each focus lens is adjusted to focus the beam eight target radii beyond the center of the target.

An overall assessment of the illumination uniformity achieved on a spherical target is made with a new spherical, 2-D, beam-superposition code.[11] This code maps the overall intensity distribution on a spherical target, utilizing the individual 2-D intensity distributions recorded for each beam with the correct beam orientation, beam geometry, and focusing conditions; azimuthal averaging is not applied to the beam profiles.

For composite six-beam distributions it is assumed that the total laser energy is divided approximately equally among all six beams.

Contour interval = 0.12 × max intensity

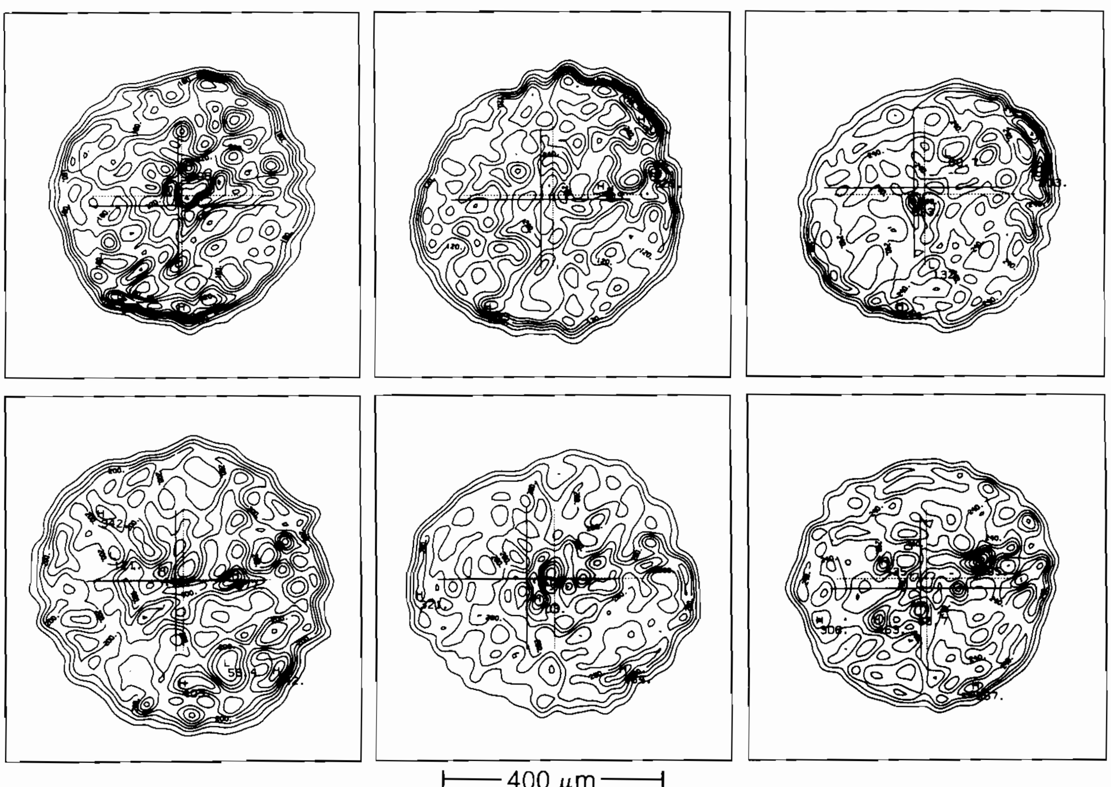

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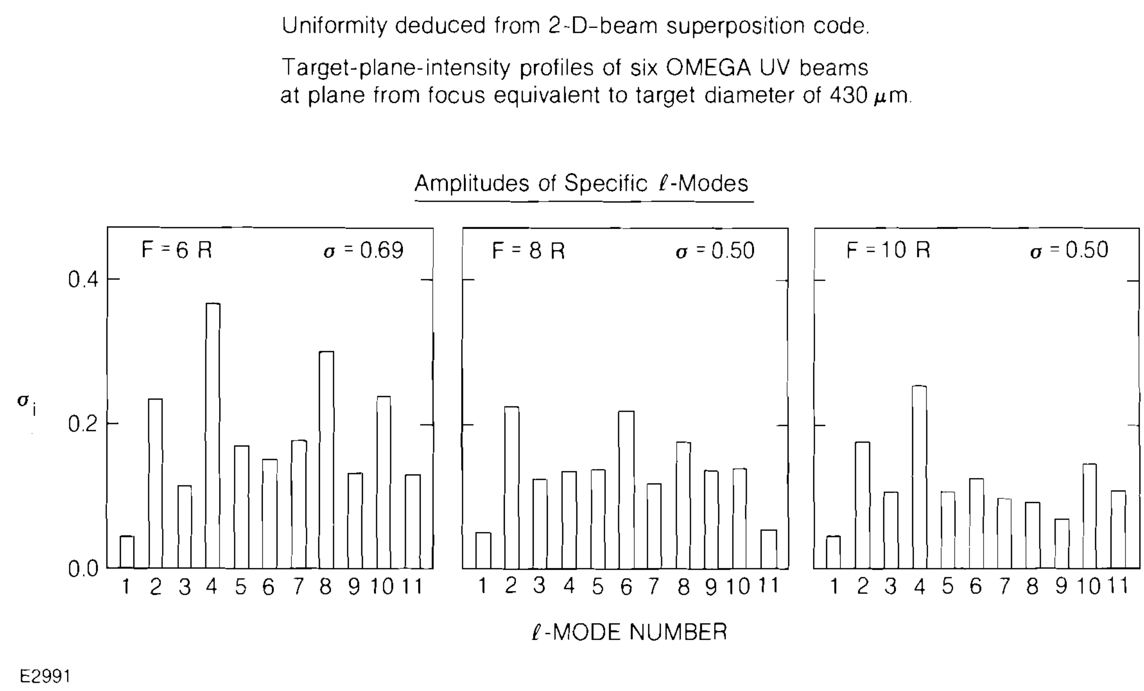
Fig. 20.8
Iso-intensity contour plots of the intensity distributions in all six UV beams at a distance of 1600 μm from best focus. This corresponds to the intensity distribution of each beam when focused for tangential overlap on a 400-μm-diameter target.

The actual minimum beam-to-beam energy variance in OMEGA depends upon the accuracy of the energy-measurement system. Precise reapportionment of the beam-output energies is currently limited by the MESS-diode calibration variance. This is due, in turn, to residual electrical and thermal noise in the signal from the thermoelectric calorimeters used to calibrate the diodes. With the present calorimeter-calibration uncertainty, it is possible to balance the on-target energies of the six UV beams to ≈ 3% rms, so the assumption of equal beam energies is valid.

In order to assess nonuniformity quantitatively for specific beam-focusing conditions, the corresponding surface intensity distributions are decomposed into spherical-harmonic modes.[3] The amplitudes of the low-order ℓ-modes are significant in determining the reaction of imploding laser-fusion targets to irradiation nonuniformities. Low-order ℓ-modes correspond to large-scale irregularities which will tend to be accentuated as the target implodes. Higher-order ($\ell > 20$) modes are not expected to affect the implosion greatly, since they correspond to small-scale fluctuations that will be reduced by thermal smoothing.

Shown in Fig. 20.9 are the amplitudes of the first 11 ℓ-modes for three different focusing conditions with six UV beams on target. The level of nonuniformity, taken as the quadrature sum of the first 11 ℓ-mode amplitudes, decreases as expected when the focus parameter is increased from 6 R through 8 R (tangential focus). If there were

Fig. 20.9
Decomposition of the intensity distribution shown in Fig. 20.8 in terms of the amplitudes of specific, low-order, spherical harmonic modes. The level of non-uniformity, as depicted by the amplitude of specific ℓ-modes, decreases as the beams are focused further beyond the target.



more than six beams, the nonuniformity at 10 R would be less than at 8 R. Here, the focus parameter is the number of target radii beyond the center of the target at which the geometric focus of the beam is located. The level of nonuniformity estimated for six IR beams for identical focus parameters is comparable.[12]

These nonuniformity estimates are base-line data for measuring future improvements in irradiation uniformity. Considerable improvement is expected as a result of converting all 24 beams to the UV. In addition, we are working to improve our control of the intensity distribution in each beam and to reduce the beam-to-beam energy imbalance.

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