ACKNOWLEDGMENT

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1.C Precise Control of the OMEGA Laser

The current experiments relevant to the demonstration of inertial confinement fusion require that the target driver be capable of precise control. To control the driver, diagnostics are needed to measure its performance. The OMEGA laser has been through a series of improvements allowing the system to be configured for a specific series of target experiments. These techniques give a well-characterized and reproducible illumination pattern to an implosion target.

OMEGA Energy Balance

The beam-splitting control system on the OMEGA laser has been improved[1] allowing the energy in each of the 24 beams to be balanced with a root-mean-square error of 1%–2%. The primary components of the balance control are computer-controlled wave plates whose rotation is determined by the output of 24 silicon PIN diodes. A schematic of the control system is shown in Fig. 43.18.

The splitter wave plates on OMEGA are now motorized and can be positioned by a PDP-11 minicomputer. The motor controllers are linked together by a parallel signal cable from the computer interface. Each wave plate has a unique address on the bus and as such can be addressed separately. During a beam-balancing sequence, the minicomputer determines the needed setting of the individual wave plates and then sequentially sets the rotation until the desired system split is achieved.

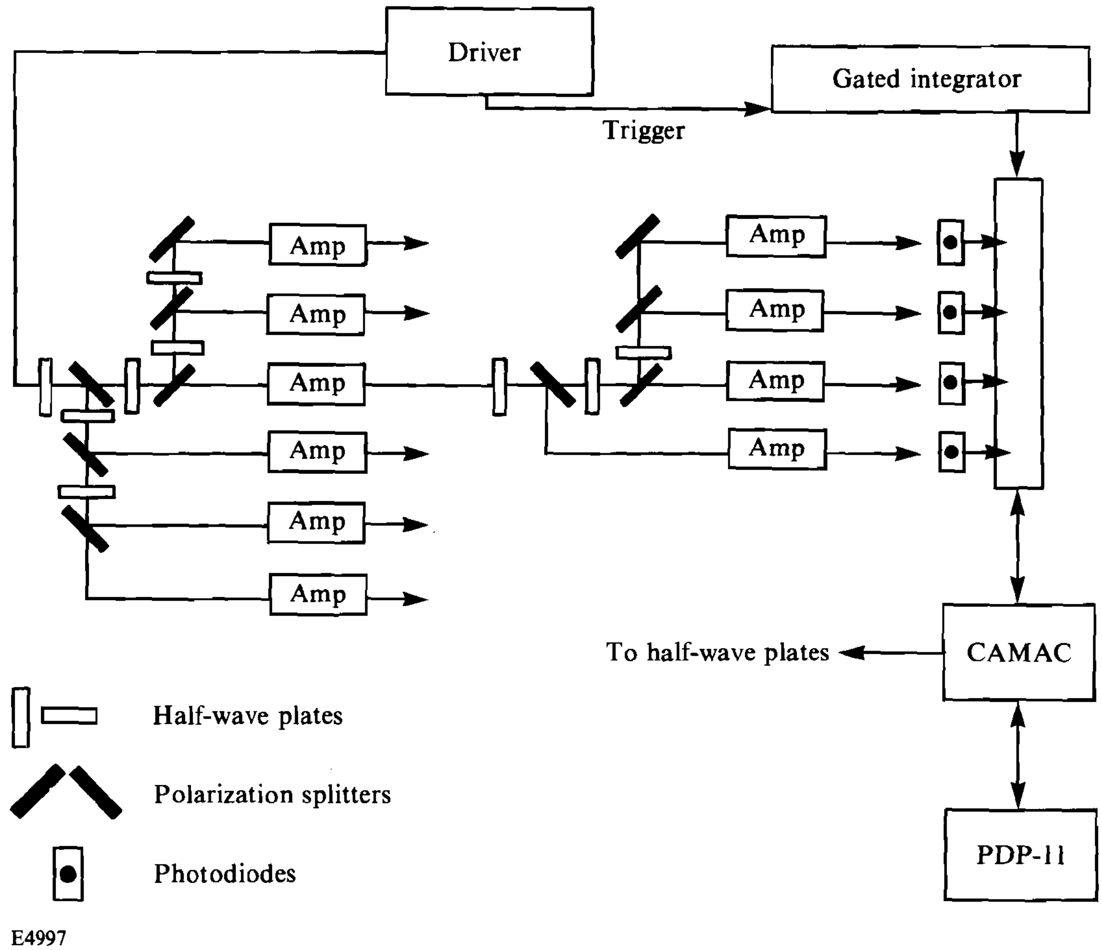

Fig. 43.18
The OMEGA automatic beam-energy-balance system. This system consists of a set of computer-controlled half-wave plates whose rotation is determined by the output of silicon PIN photodiodes.

There are 24 silicon PIN diodes used to determine the rotation angle for the wave plates. These diodes have a Fresnel lens at the input that couples the inner 60% of the beam area to the detector. The detectors are designed to be sensitive to the main OMEGA oscillator, which does not need to be amplified. This allows the laser system to be balanced with a 1-Hz repetition rate. The energy, as reported by on-line calorimetry from previous full system shots, is used as a reference and the minicomputer adjusts the wave plates for the required PIN-diode signal levels.

By using the oscillator, PIN diodes, and motorized wave-plate controllers, the OMEGA laser can have its energy split set during a 1/2-h shot cycle. This procedure can be used to either balance the laser beams or set up a specific energy distribution. The effects of low-order nonuniformity of laser illumination during a direct-drive target implosion can be determined by inducing a known energy distribution on the OMEGA laser. A reference table on individual beam energies can be used to set the wave-plate rotation for the desired illumination distribution.[2]

Due to these improvements in the energy-distribution control, OMEGA can now be used for a series of experiments that were not possible previously. The overall system-energy-balance error has been improved from 3%–5% to 1%–2%. All this can be accomplished within a single shot cycle so that, as conditions change during a shot series, the laser-system energy settings can be reestablished to the experimental requirements.

Small-Signal-Gain Measurements

The silicon diodes that are used for the energy balancing of OMEGA have been used to measure the small signal gain of each amplifier. This allows system performance to be monitored and maintenance tasks assigned when an individual amplifier is outside its performance specifications. The importance of gain control to power balance was discussed in an earlier LLE Review.[3] By using the main OMEGA oscillator and a series of calibrated neutral-density filters, it is possible to measure the gain of all amplifiers in a day. A reference diode is used to monitor the oscillator output, and the 24 energy-balance diodes are used to measure the amplified oscillator pulse. The lens used in front of the balancing diodes samples a large enough portion of the laser beam to accurately determine the amplifier gain.

It is possible to match the beamline gains by changing amplifier rods after a small-signal-gain measurement.

OMEGA Target-Integrating Sphere

To be used for experiments, the laser output must be transported to the target. The OMEGA transport system uses three to four mirrors, a distributed phase plate (DPP), a focus lens, and a blast shield/vacuum window for each beam. The reflection of each mirror and the transmission of the DPP, lens, and blast shield for all beams must be measured and monitored. The technique currently employed on OMEGA uses a small integrating sphere at the center of the target chamber to measure the UV transport efficiency.

A schematic of the measurement configuration is shown in Fig. 43.19. The output from an argon-ion laser is tuned to 351 nm and is injected into an OMEGA beam after the frequency-conversion crystals. A portion of this beam is split off into an integrating sphere as a reference. The beam is then transported to the target chamber where a second integrating sphere measures the beam energy. The ratio of the signals from these two detectors determines the transport efficiency of the beamline. The argon-ion laser beam is chopped so that a stable, high-gain, lock-in amplifier can be used to measure the energy in the transported beam.

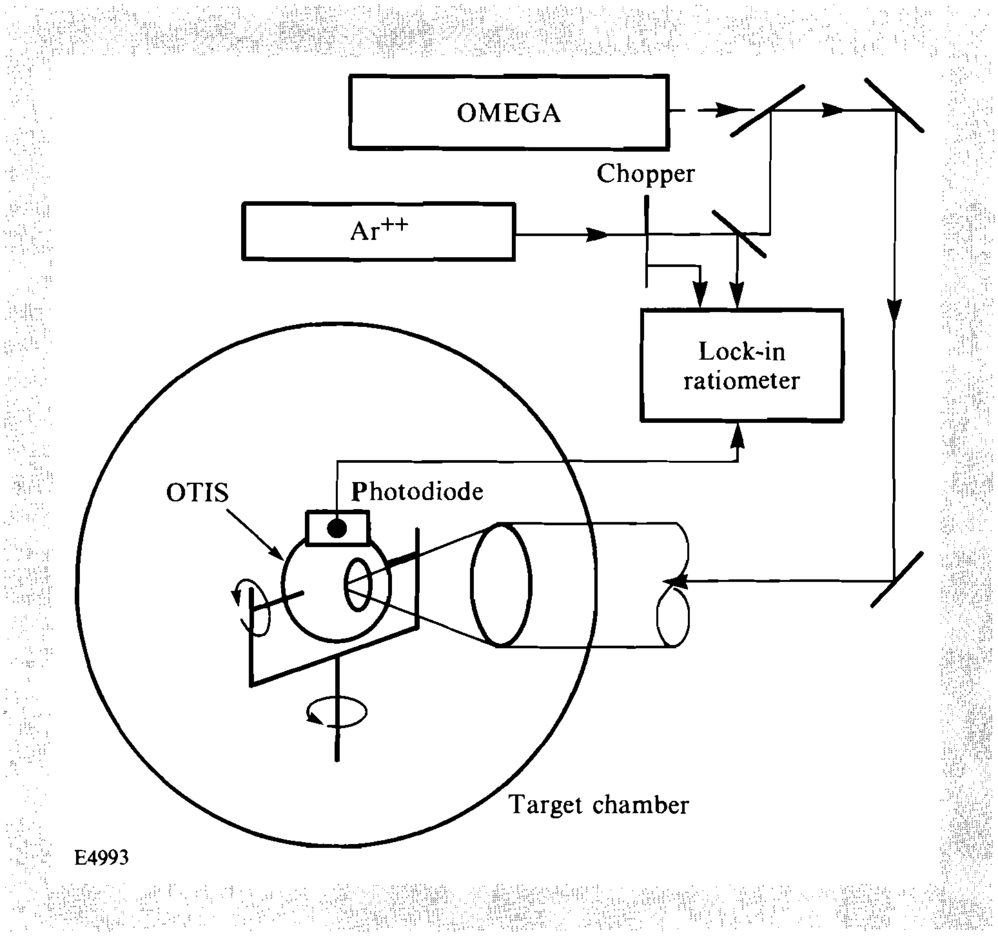

Fig. 43.19
The OMEGA transport integrating-sphere system (OTIS). An Ar^{++} ion laser is injected into an OMEGA beamline after the frequency-conversion crystals. The signal as measured at the center of the target chamber is ratioed with a reference signal to measure the transport efficiency.

The target-integrating sphere is small enough to be inserted into the target chamber without removing target diagnostics. A two-axis angular control allows the input of the sphere to be directed to each of the OMEGA beam ports. Thus, it is possible to measure the transport efficiency of all 24 beamlines in 4 h with a 1%–2% accuracy. The transport measurement is now scheduled as a routine target-chamber maintenance task with minimum impact on system operation.

Pointing with X Rays

The final pointing of the OMEGA beams is done by measuring the beam position with a gold-coated target, which is 800 μm in diameter with a 1-μm-thick gold coating. The x rays emitted by this target are measured with six reentrant pinhole cameras distributed around the OMEGA target chamber so that the position of all 24 beams can be determined. The cameras are tuned to the gold N- and M-shell x-ray emission. The 1-μm-thick Au layer is about three times the thickness that would be burned through by an OMEGA beam. This ensures that all beams are measured equally and that the layer thickness does not affect the x-ray image.

After a system shot the images are processed and digitized with a video digitizer connected to a solid-state camera, which is interfaced to a microscope with a magnification of 3. This same system is used for the measurement of "knock-on" data from an OMEGA implosion target.[4] An image from a pointing shot is shown in Fig. 43.20. The x-ray image shown in Fig. 43.20(a) is taken before the system pointing has been corrected. The root-mean-square pointing error is 18 μm with the worst beam mispointed by 31 μm. A table of corrections for the positions of each targeting mirror is generated and used to repoint the beams. Figure 43.20(b) shows an image after this correction has been made. The rms pointing error is now 10 μm and the worst error is 22 μm. These errors are measured on the surface of the 800-μm-diam pointing target. This procedure is repeated until the rms pointing error is less than 10 μm and the worst beam is displaced less than 20 μm from its optimum position. The time between pointing shots is about 1 to 1.5 h and includes the time needed for film processing, digitization, measurement, and mirror correction of 24 beams. A full shot day is allocated to point the system when it is initially started at the beginning of a shot week. Pointing is checked at the start of each shot day, when only small corrections are needed.

(a) Shot 19457 (b) Shot 19461

σ_{rms} = 18 μm
Worst = 31 μm
Median = 15 μm

σ_{rms} = 10 μm
Worst = 22 μm
Median = 7 μm

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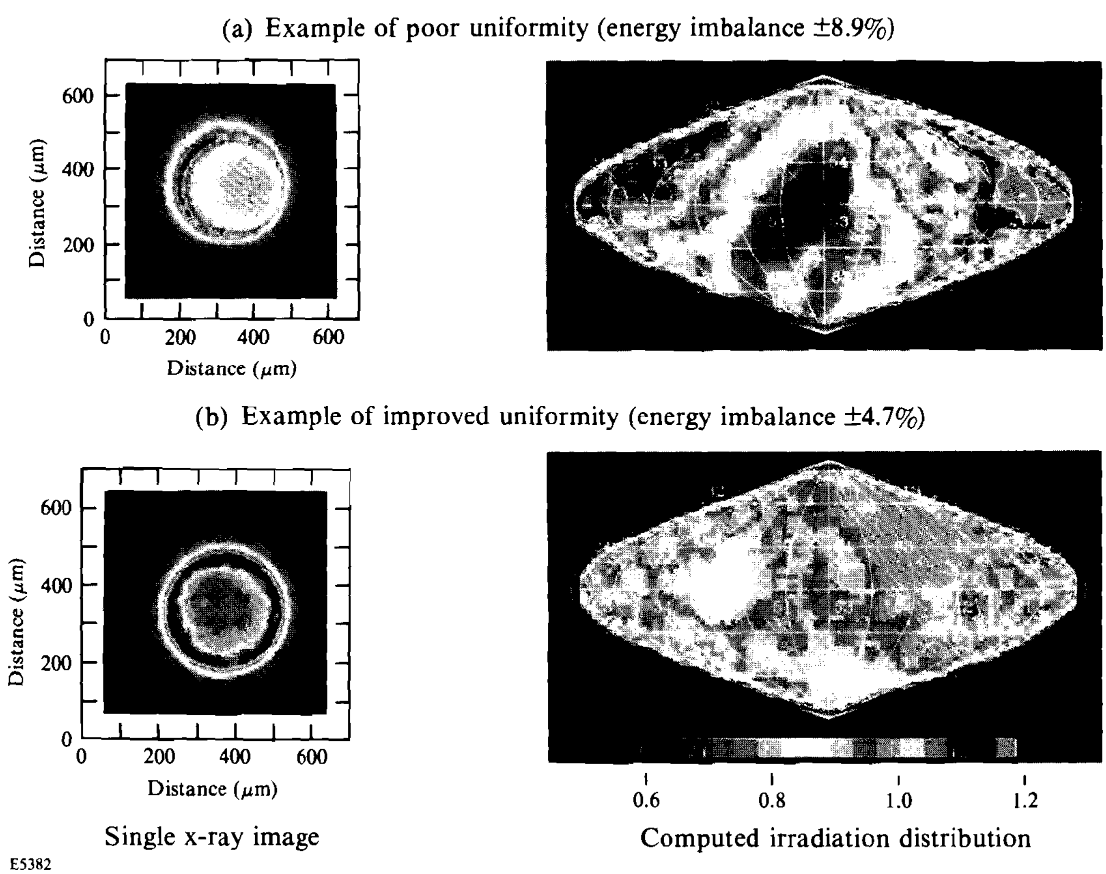
Fig. 43.20
Final laser pointing using x-ray images. The x-ray emission from Au-coated targets is used to measure the position of each beam on a sphere. This image is used to arrive at a set of corrections for the position of each targeting mirror.

Target Drive Uniformity

The illumination uniformity of the laser is checked by measuring the x-ray emission from a small implosion scale target. This target is 250 μm in diameter with a 1-μm-thick layer of gold coated on the outside. The 250-μm diameter is matched to the diameter of the OMEGA implosion targets and as such serves as a good measure of the drive conditions. The x rays are measured with both the reentrant pinhole cameras and the Kirkpatrick-Baez microscopes. The images are then digitized with a photographic digitizer interfaced to a SUN workstation.

Uniformity images are shown in Fig. 43.21. Figure 43.21(a) shows an image taken before all improvements in the OMEGA controls were implemented. The energy was balanced to ±8.9% rms and is an example of very poor drive uniformity. The projected image is a sinusoidal projection that preserves the area on the sphere. It is evident that there are 100% peak-to-valley intensity variations in the laser illumination. An example of a ±4.7%-rms-energy-balanced laser system is shown in Fig. 43.21(b). The improved uniformity is apparent in the projected image. The peak-to-valley variations are about 20%. A sinusoidal projection is made from three

Fig. 43.21
A record of illumination uniformity is taken with an x-ray image of a target having the same diameter as an implosion target. At least two individual images are used to arrive at a sinusoidal projection of the intensity distribution for the entire target.



individual camera images. An example of a single image is shown adjacent to the projected images. These targets allow the drive conditions to be monitored on each shot day.

Summary

Improvements to both laser control and diagnostics have allowed the OMEGA laser to be used with greater precision than previously possible. The automatic splitting of the OMEGA beams is essential in the setup and stability of the system. The current energy balance of 1%–2% is well characterized at the output of the frequency-conversion cells. The energy is then transported to the target using transport optics that are characterized to 1%–2% with an integrating sphere inside the target chamber. This gives an overall system-energy balance of 1.5%–3% rms. The final laser pointing uses x-ray images to optimize the system for target shots. The illumination uniformity for each shot day is characterized using an x-ray-emitting target that is the same size as an implosion target. All of these techniques are essential to perform the relevant target experiments to demonstrate the capabilities of inertial confinement fusion.

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