Section 2
PROGRESS IN LASER FUSION

2.A OMEGA Energy Measurement

Maintaining beam balance, i.e., the equality of on-target energy in each of OMEGA's beams, to within 1% rms is one of the major requirements for illumination uniformity.[1] Provision for balancing beam energies was incorporated into the system design during the construction of OMEGA. Half- and quarter-wave plates are located at most of the dielectric-coated beam splitters and at all of the polarizers in the beamline. With these waveplates, we adjust the polarization of the beams to vary the ratio of transmitted to reflected energy at the beam splitters or to reject some of the energy at the polarizers. Thus, energy is either redistributed among the beams or simply dumped. A computerized beam-balance procedure uses measured beam energies and current wave-plate settings as input data and calculates new wave-plate settings to improve the balance of beam energies. The principal limit to precise beam balance is the accuracy of the individual beam energy measurement.

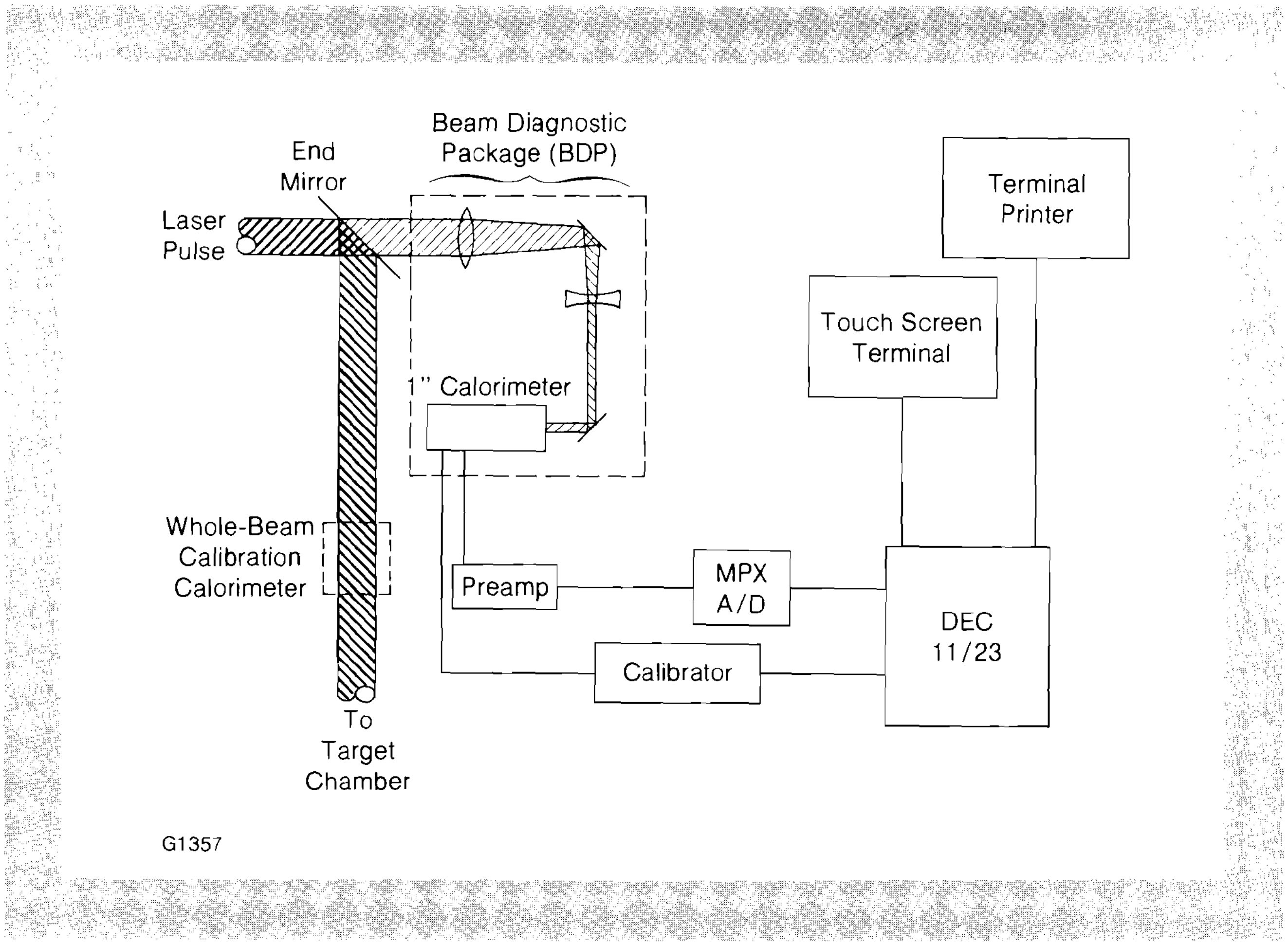
Energy Measurement at 1054 nm

Our attempts over the last two years to maintain balanced beam energies resulted in 5-10% rms balance on routine shots. Random 5% fluctuations in the relative individual beam energies occurred on a shot-to-shot basis and within a few weeks, the beam balance drifted 15-20%, necessitating energy rebalance. As we addressed the problem of precise beam balance, it became clear that some of the fluctuations were due to noise and drift in the energy measurement system. The first necessary step was to characterize the beam-energy measurement system and determine if the relative energy of the beams could be measured to within 1%.

The primary instruments for measuring laser energy are volume-absorbing calorimeters which use a thermoelectric element to convert the thermal signal to an electrical signal.[2] The response of the calorimeter is proportional to the energy in a laser pulse. Detection sensitivity is determined with calibrated electrical pulses heating an internal heater winding in the calorimeter.

The technique for measuring laser energy during a target shot consists of diverting a small fraction of the beam energy to a calorimeter. Main beam energy is the product of a calibration coefficient and the sample energy measured by the calorimeter. Calibration is carried out by firing the whole beam into a large-aperture (8″) calorimeter which has been set up temporarily in the beam path. The calibration coefficient is then determined as the ratio of measured whole-beam energy to sample energy. The optical configuration for calibration of OMEGA at 1054 nm is illustrated in Fig. 18.1. Approximately 1% of the incident laser pulse is transmitted through the end mirror into the beam-diagnostic package (BDP). About 80% of the BDP input energy is sampled by a 1″-aperture

Fig. 18.1
Schematic of the OMEGA energy measurement system for 1054 nm. A small fraction (~ 1%) of the laser beam is transmitted through the end mirror to the beam-diagnostic package (BDP), and approximately 80% of this energy is measured by the 1″ calorimeter. The system is calibrated by placing an 8″ calorimeter in the beam after the end mirror.



calorimeter. The 8″ calorimeter is set up immediately after the end mirror for calibration. Figure 18.1 also depicts the other major elements of the OMEGA laser-energy measurement system. The low-level calorimeter output is amplified and transmitted to a minicomputer via a multiplexed A/D converter. Reduced data are summarized in a report on the terminal printer and stored on disc along with the acquired data. The same computer also fires the electrical calibrator on command for calorimeter calibration and system checkout.

The precise measurement of laser energy depends on the reliability of the 8″ reference calorimeters. Thus, the first task in the beam-balance investigation was to measure the reading consistency and the relative optical sensitivities of the 8″ calorimeters. In a special test series, the 8″ calorimeters were set up and exchanged in a systematic fashion among OMEGA beams. The following are the results of a careful analysis of the 8″ and 1″ calorimeter data from these tests.

(a) Measured optical sensitivities of the 8″ calorimeters differed from their measured electrical sensitivities, by as much as 4%.

(b) Shot-to-shot fluctuation of the energy ratios of paired calorimeters in the same beam or in different beams was about 5% rms.

(c) Relative optical sensitivity appeared to be a function of the beam energy in some cases (insufficient data for quantitative statistics).

We identified two principal causes of the random variability. First, an oscilloscope on the A/D input terminals revealed that the slow calorimeter signals were superimposed on high-frequency noise. The source of some of this noise was traced to the adjacent computers and switching-mode power supplies. This common-mode noise should have been rejected by the A/D, but was not. After concluding that this was an inadequacy in the design of the A/D converter rather than a malfunction, we replaced the A/D converters with those of another manufacturer. The second source was long-term thermal drift due to local air circulation at the calorimeter. Thoroughly insulating the calorimeter and adding a close-fitting input window eliminated this problem.

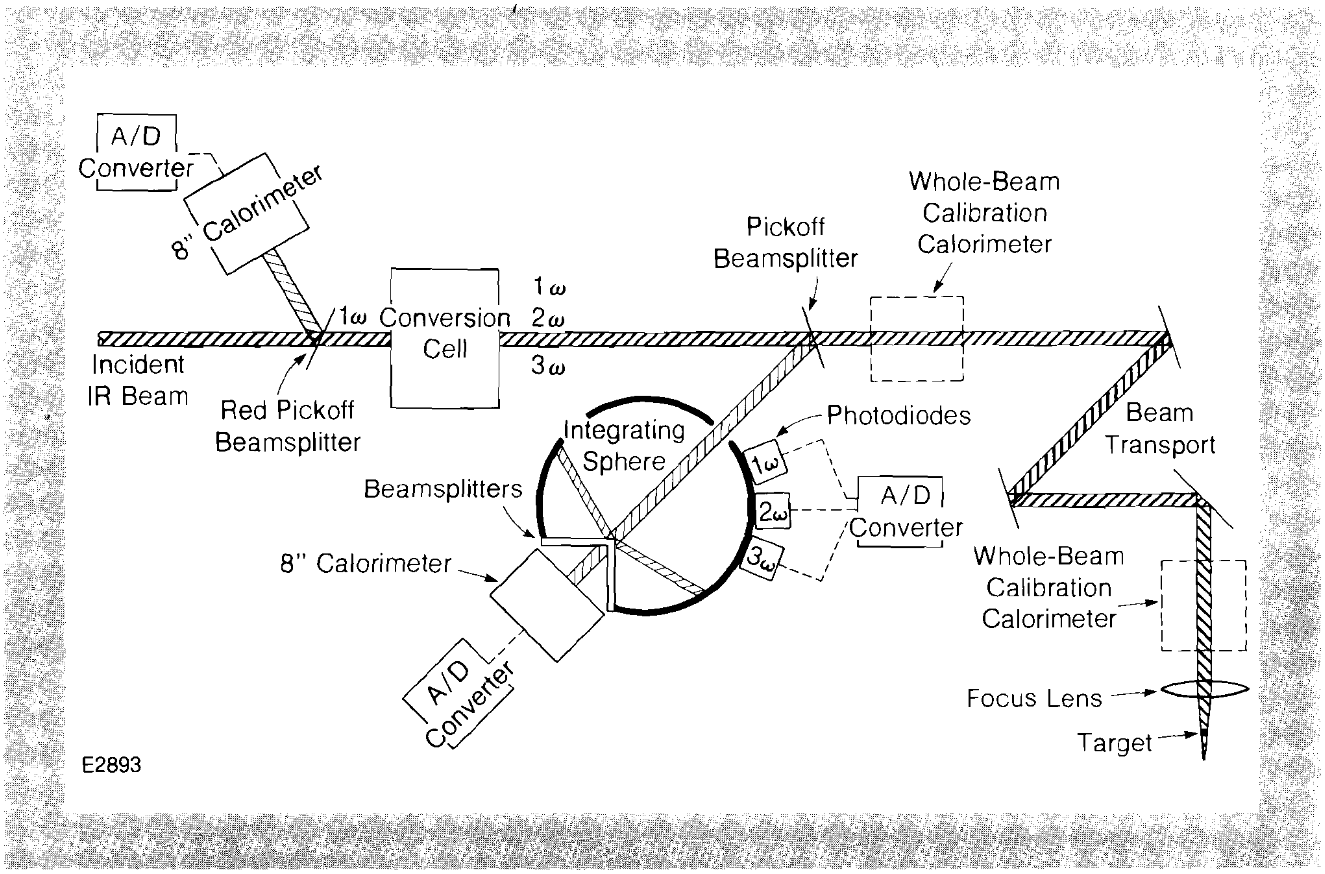
In addition, we began to suspect that the non-constant sensitivity might be an effect of the end-mirror coatings. These high-reflectivity (HR) coatings transmit about 1% of the "P" polarization and much less of the "S" component. Therefore, very small variations in reflectivity represent very large variations in transmission (e.g., a 1% decrease in reflectivity is a 100% increase in transmission for a 99% reflective coating). Initially, we thought that water vapor might be affecting the transmissivity of the coatings. However, upon investigation of the effect of ambient humidity, we concluded that this effect was negligible. This did not rule out coating effects because spatial variations in coating transmissivity could cause the energy fraction reaching the calorimeter to vary as the beam profile or the beam alignment was changed.

Energy Measurement at 351 nm

Further characterization of the energy measurement system was deferred until the first six beams of OMEGA were converted to UV. New A/D converters and repackaged 8" calorimeters (with windows and improved insulation) were designed into the UV energy measurement system to minimize the effects of the identified noise and drift sources. The calorimetry system has been retested in the same manner used at 1054 nm and a measurement consistency of 1% rms has been measured, thus confirming the elimination of the major drift and noise sources.

Fig. 18.2
Schematic of the OMEGA energy measurement system for 351 nm. Energy pickoffs operate at small angles of incidence and use uncoated first surfaces and antireflection (AR)-coated second surfaces. The conversion-cell output energy at 1ω, 2ω, and 3ω is measured with photodiodes mounted in an integrating sphere. Full-aperture, 8" calorimeters are used to measure the incident 1ω beam and to cross-check the diodes. Separate 8" calorimeters are inserted in the beam to calibrate the system. Energy transport to the target is measured by inserting a 351-nm bandpass-filtered calorimeter in the beam in front of the focusing lens.

Energy diagnostics of frequency-tripled beams present some new challenges. Figure 18.2 illustrates the final configuration of the UV energy measurement system. A beam splitter was installed, at a low angle of incidence, in the beam between the last spatial filter and the conversion cell. The 4% reflection from the uncoated first surface is measured by a dedicated 8" calorimeter. The second surface is antireflection (AR) coated to minimize the insertion loss of the pickoff. The combination of an uncoated surface and the low angle of incidence was used to minimize any effect of beam profile change or beam misalignment. Considerations of available space, alignment stability, optical sensitivity, and cost per channel led us to specify an array of three photodiode detectors for the conversion-cell output measurements. The photodiodes we selected have fast response and excellent sensitivity and linearity at the three wavelengths of



interest. These properties were confirmed in laboratory tests at LLE as part of the system design procedure. The three photodiodes are mounted on the surface of an integrating sphere, and appropriate filter stacks in front of each diode select one of the three output harmonics and attenuate the optical signal. The input to the integrating sphere is another Fresnel reflection from a fused-silica beam splitter in the conversion-cell output beam. This diagnostic beam enters the integrating sphere through a baffled input aperture to minimize stray-light noise. At the back of the sphere the beam strikes a wedged fused-silica beam splitter which reflects 8% of the light onto the diffusing inner surface and transmits 92% of the light to an unfiltered 8″ calorimeter. The integrating-sphere calorimeter measurement is a check on the energy sum of the diode channels, and it provides a backup in case one of the three diode channels should fail.

We calibrate the MESS (Multi-Wavelength Energy-Sensing System) against the response of an 8″ calorimeter set up temporarily in the main beam following the MESS pickoff as shown in Fig. 18.2. First, the tripling cell is detuned to minimize harmonic conversion, then the cell is tuned to generate 2ω light, and then the tripler is tuned for maximum 3ω generation. Simple linear regression analysis yields the diode calibration coefficients in joules/count. UV diode calibrations are rechecked from time to time with an 8″ calorimeter fitted with a UV transmitting filter. We selected the diodes and designed the system for less than 1% rms measurement consistency; however, the UV diodes are currently calibrated to ±3% rms at full OMEGA output. Further measurements of the diode subsystem are in progress. The UV calorimeter assembly is also set up at the final focus lens to measure the transmission from the MESS pickoff to the target (see Fig. 18.2). This is required for accurate measurement of the UV energy on target.

Summary

Experience with the revised and augmented energy measurement system has been encouraging. Eight-inch calorimeter statistics demonstrate a consistency of 1% or better measurement accuracy for fixed output energy. There is some indication, however, that optical sensitivity may be a weak function of energy. We have designed a precision electrical calibrator to enable us to determine the absolute sensitivity of the calorimeters as a function of deposited energy over a range of 1 to 100 J. This device will help resolve this question of linearity. The photodiode subsystem, totally new in OMEGA, is rapidly attaining full operational status, although it has not reached the 1% rms precision required. Confirmation of improved diode precision is still pending, but we are confident that we can perfect this subsystem.

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