Section 1
PROGRESS IN LASER FUSION

1.A A Strategy for Laser-Beam Power Balance on the OMEGA Upgrade

One of the requirements for the OMEGA Upgrade laser system[1] is that it deliver its energy to the target with an irradiation perturbation caused by power imbalance of 1% or better.[2] This requirement is based on results from two-dimensional computer simulations in which OMEGA Upgrade high-gain targets were driven by a spatially perturbed laser-irradiation distribution resulting from beam power imbalance. Such a distribution, which consists mainly of low-order Legendre modes (<20), produces an implosion asymmetry that grows secularly and has the potential for reducing the target performance by mixing pusher and core material.[3] It is, therefore, necessary to control the irradiation power balance throughout most of the laser pulse.

The OMEGA Upgrade consists of 60 beams produced by three sets of beam splitters, A, B, and D, as shown schematically in Fig. 52.1. (The D splitter is actually composed of two different splitters separated by a spatial filter. This is treated as a single splitter in the power-balance analysis.) A set of splitters and the associated optics and amplifier(s) are defined as a splitter group. The laser pulse, shown in Fig. 52.2, is comprised of a slow-rising, low-power foot pulse and a fast-rising, high-power main pulse. The two pulses are coaxially propagated through the laser system, with the foot pulse in the center and the main pulse on the outside. Since several beams overlap on target, the 1%-rms power-balance requirement over the target surface is equivalent to a 3%–5% beam-to-beam requirement at the output of the laser beams. This power-balance level is needed throughout the last half of the foot pulse and through the early part of the main pulse.[3]

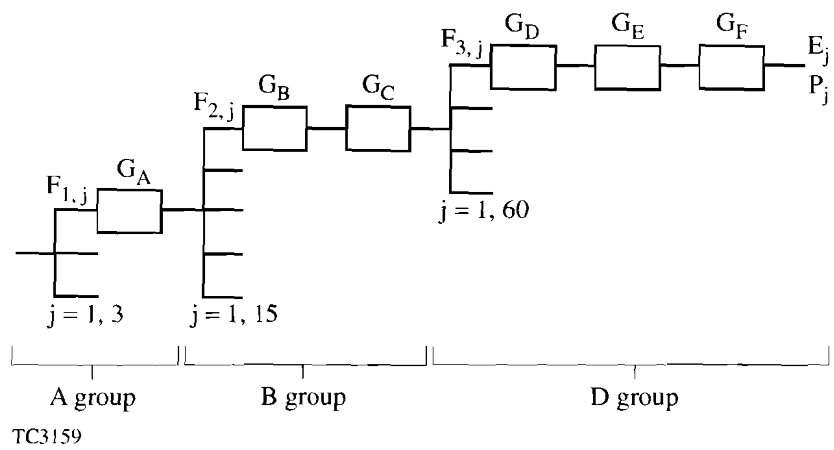


Fig. 52.1
Schematic of the OMEGA Upgrade laser system and notation used in the analysis of the power-balance model.

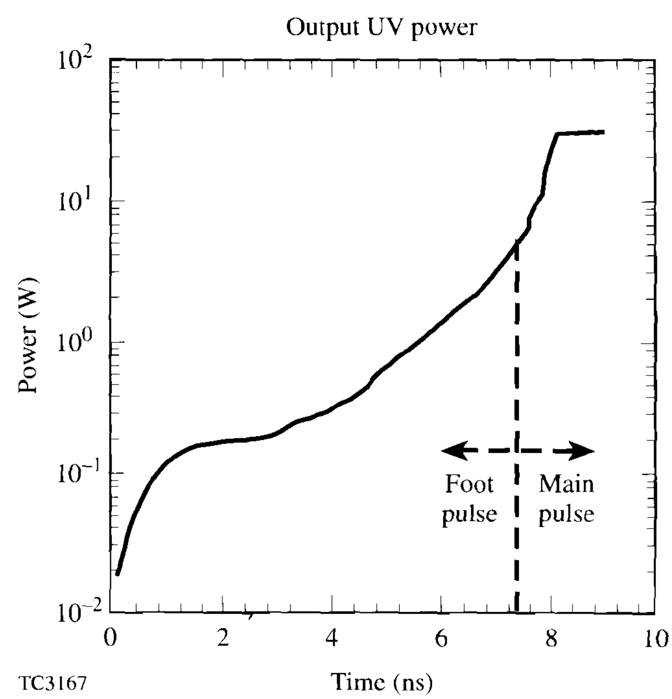


Fig. 52.2
Typical temporal UV pulse shape for high-gain target experiments. The pulse is divided into a low-intensity foot pulse and a high-intensity main pulse. The two pulses are propagated coaxially, with the foot pulse inside the main pulse.

In this article we present a strategy to obtain power balance on the OMEGA Upgrade in which the output energy and the peak power are measured and the D-splitter fractions and the F-amplifier gain (G_F in Fig. 52.1) are adjusted. Only the contributions to power imbalance caused by beam-splitter setting variations, variations of the amplifier voltages, and inaccurate knowledge of the losses in the beamline are considered. Other contributors to power imbalance, such as variations in beam areas (that affect the frequency-conversion efficiency), conversion crystal settings, and beam timing, are not considered.

This article is divided into four sections. (1) Conditions of the strategy and the equations relating the output energy and power in terms of split fractions and amplifier gains are presented; (2) the laser propagation model is described and the dependence of the output energy and peak power on the split fractions and amplifier gains is presented; (3) a description of the method and a presentation of the results follows; and finally (4) we present a discussion of limitations and our conclusion.

General Principles

Any method for obtaining the desired power balance would be subject to the following practical constraints: First, tuning of the energy and power balance must be done only on the basis of known and controllable variations in the split fractions and amplifier gains because initial settings are not accurately known. Second, the only place where beam measurements can be accurately made is at the output of the last amplifier (IR measurement) or at the output of the frequency-conversion crystals (UV measurement). No accurate measurements can be carried out at the beam splitters or after any amplifier because there is not enough space between the laser components for deploying the instruments. Third, the only two beam-to-beam quantities that can be measured with a relative accuracy of a few percent are the total energy and the peak power. Finally, the power-balance tuning must be carried out with the least number of full-power shots (five or less) and with the smallest amount of component manipulation (varying split fractions or amplifier voltages).

Power balance in the case of the OMEGA Upgrade laser is complex because the 60 final beams are coupled through the three sets of splitters. Therefore, the input to each chain cannot be independently controlled. Another constraint on the control of the input energy is that the sum of the split fractions must evidently be equal to or less than unity. It is possible for the sum of the split fractions to be less than unity because the reflectivity of the individual mirror is controlled by its angle with respect to the beam. In such a case, laser energy is discarded. The most general form of a transfer equation for the output energy E_j and peak power P_j of the j^{th} output beam in terms of the split fractions $F_{i,j}$ and the small-signal gain $G_{i,j}$ in the last amplifier in each splitter group (amplifiers A, C, and F, respectively) is given by

$$\Delta E_j = \sum_{i=1}^{3} \left\{ \left(\frac{\partial E_j}{\partial F_{i,j}} \right)_{G_{i,j}} \Delta F_{i,j} + \left(\frac{\partial E_j}{\partial G_{i,j}} \right)_{F_{i,j}} \Delta G_{i,j} \right\}$$

$$\Delta P_j = \sum_{i=1}^{3} \left\{ \left(\frac{\partial P_j}{\partial F_{i,j}} \right)_{G_{i,j}} \Delta F_{i,j} + \left(\frac{\partial P_j}{\partial G_{i,j}} \right)_{F_{i,j}} \Delta G_{i,j} \right\} , \tag{1}$$

where ΔE_j is the variation in the output energy of the j^{th} beam, ΔP_j is the variation in the peak power of the j^{th} beam, $F_{i,j}$ is the split fraction of the i^{th} splitter (A, B, and D) and the j^{th} beam of the splitter, and $G_{i,j}$ is the small-signal gain of the last amplifier in the j^{th} beam of the i^{th} splitter group. The index i is over the three splitters in the most general case. Although the functional dependence of the output energy and peak power with split fraction and F-amplifier gain is far from linear over the entire range of the dependent variables (see the following), we assume that it is linear over the range through which the quantities will be varied during the power-balance tuning:

$$\Delta E_j = \sum_{i=1}^{3} \left[a_{i,j}\, \Delta F_{i,j} + b_{i,j}\, \Delta G_{i,j} \right]$$

$$\Delta P_j = \sum_{i=1}^{3} \left[c_{i,j}\, \Delta F_{i,j} + d_{i,j}\, \Delta G_{i,j} \right] , \tag{2}$$

where the constants $a_{i,j}$, $b_{i,j}$, $c_{i,j}$, and $d_{i,j}$ can be obtained by varying each split fraction $F_{i,j}$ and each amplifier gain $G_{i,j}$ while keeping the other components constant, and measuring the change in the output energy and peak power. To this set of equations must be added the requirement that the sum of the split fractions (k) in a given splitter cluster (i) be unity:

$$\sum_{k} F_{i,k} = 1 . \tag{3}$$

The upper limit of the sum depends on the splitter: it is 3 for the single A splitter, 5 for each of the five B splitters, and 4 for each of the 15 D splitters.

There are several methods by which the power balance could be obtained. The most general way is to solve the entire set of 139 linear equations, 120 given by Eq. (2) and 19 from Eq. (3) for each splitter. The independent variables are the 78 split fractions (see Fig. 52.1: 3 + 15 + 60) and the small-signal gains from the 60 F-amplifers for a total of 138. The missing variable could be the average output energy (see the following). The dependent variables are the 60 laser-output-energy values and the 60 peak-power values. Another method is to balance each split cluster starting with the D-splitter groups. First, both the energy and the peak power are balanced for each of the four beams in each of the D-splitter groups by varying the splitter fractions and the F-amplifier gain. This leaves 15 unbalanced beams in the B-splitter group. Each of these 15 beams is then balanced by using the output energy and the peak power summed over each of the D-splitter groups. The three unbalanced beams in the A-splitter group are then balanced by using the output energy and the peak power summed over the three groups of 15 beams. A third method is an iterative scheme in which the laser beams are first balanced for output energy by varying the split fractions and then balanced for peak output power by varying the F-amplifier small-signal gain. In all the methods, measurements need to be carried out with full-power shots since the large-signal gain differs significantly from the small-signal gain because of saturation effects.

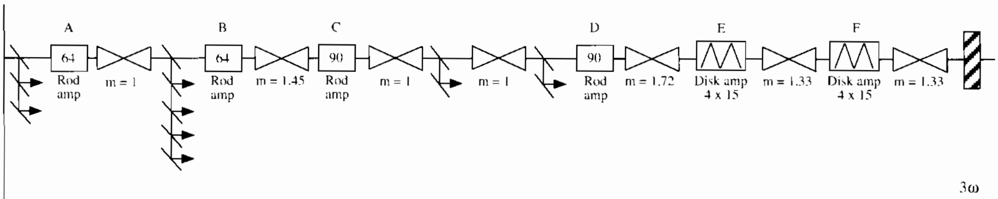
Modeling and Results

To simulate the various possible schemes, beam propagation through the OMEGA Upgrade laser is modeled with a one-dimensional code in which the foot pulse and the main pulse are propagated separately. Both the laser beam and the amplifiers are divided into small slices in time and space, respectively. From the given initial amplifier gain $G_0 = \exp(\alpha_0 L)$, where α_0 is the initial gain coefficient and L the amplifier length, the initial gain per amplifier slice is calculated as $\Delta G_0 = \exp[\ln(G_0)/N]$, where N is the number of amplifier slices. The first step in the transport of the beam through an amplifier is to modify the input fluence by the energy split fraction, any beam expansion, and the losses associated with that amplifier. When the beam is transported through the E and F amplifiers, the input fluence is reduced by a factor of 1.5 because the disks are tilted at a 45° angle. The slices of the beam are then transported through the amplifier and their fluence is calculated according to $F_{out}(x, t) = F_{in}(x, t) \exp[\Delta G(x, t)]$. Gain depletion in an amplifier slice is taken into account by decreasing the stored energy in the slice by the amount given to the beam. At the end of the chain, frequency conversion is calculated from a third-order polynomial fit to the conversion efficiency as a function of the laser intensity. Unless otherwise noted, the output energy and the peak power are "measured" after the conversion crystal from the UV output. The propagation code can also be run in the "oscillator-pulse" mode by reducing the amplifier gains to a very small value. The laser parameters used in the simulation are given in Table 52.I.

The first step in the modeling is to calculate the input laser beam that will produce the desired beam shape shown in Fig. 52.2. This is done by propagating the pulse in Fig. 52.2 backward through a single chain with nominal component settings. The resulting foot and main pulses are displayed in Fig. 52.3. The foot pulse is a fast-rising pulse that is monotonically increasing until it is cut off at the start of the main pulse. The main pulse starts at a lower value than the end of the foot pulse because the gain for the first photon is larger than the large-signal gain that controls the end of both pulses. The junction of the two pulses will not be addressed here.

The dependence of the output energy per beam on the split fraction of the A, B, and D splitters and on the amplifier gain of the A, C, and F amplifiers is shown in Fig. 52.4. Similarly, the dependence of the peak power on the split fractions and amplifier gains is shown in Fig. 52.5. The dashed curves and lines are the nominal operating conditions, which are the perfect split fraction and the nominal gain of the amplifiers as listed in Table 52.I. For ease of comparison the curves are plotted over the same range of axis values and the gains are varied over a 50% range. The effects of gain depletion and saturation are evident from the leveling of the output energy and from the ultimate decrease of the peak power

Table 52.1: Parameters of the OMEGA Upgrade laser. Two splitters between the C and the D amplifiers were treated as a single four-way splitter. The performance numbers were obtained with more detailed propagation code than the one used in this article.



Transmission	0.31	0.88	0.99	0.17	0.88	0.99	0.85	0.99	0.47	0.99	0.47	0.88	0.96	0.96	0.99	0.95	0.99	0.97
Main pulse																		
First photon gain			16.0		16.0		9.0					9.0		4.2		3.0		
Energy (J)	0.45	5.2	5.2	1.0	11.0	11.0	69	68	34	33	16	94	93	320	310	740	730	615
Avg. fluence (J/cm^2)	.065	0.61	0.61	0.11	1.0	0.47	2.3	2.3	1.1	1.1	0.52	2.5	0.83	2.8	1.55	3.65	1.8	1.6
Foot pulse																		
First photon gain			9.6		9.6		6.4					6.4		4.2		3.0		
Energy (J)	0.54	4.0	4.0	0.75	5.4	5.3	22	22	11	10	5.1	21.5	21	70	69	160	160	82
Avg. fluence (J/cm^2)	0.81	1.3	1.3	0.24	1.7	0.79	3.2	3.2	1.6	1.5	0.72	2.9	1.1	3.4	1.9	4.3	2.1	1.2

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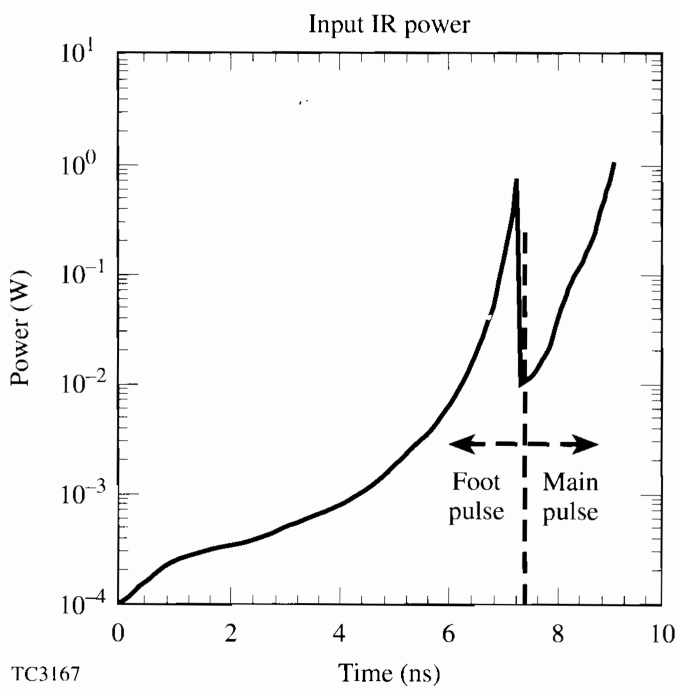

Fig. 52.3
Input IR pulse shape of the laser chain obtained by propagating the pulse in Fig. 52.2 backward. The jump at the junction of the two pulses occurs because the small-signal gain at the foot of each pulse is larger than the large-signal gain at the end of each pulse.

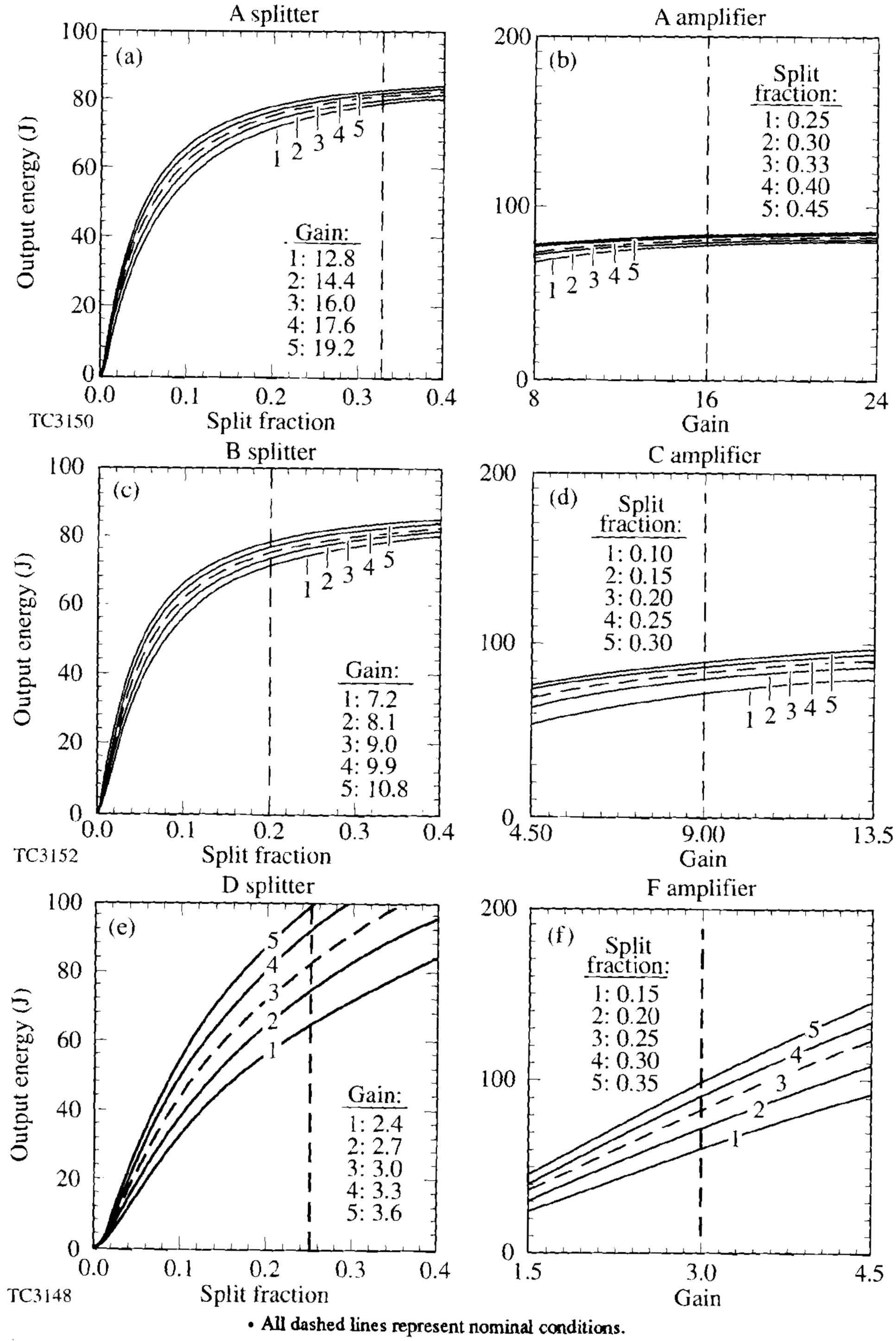

Fig. 52.4
Dependence of the output UV energy for the foot pulse on the amplifier gains and the split fractions. (a) A splitter and (b) A amplifier; (c) B splitter and (d) C amplifier; (e) D splitter and (f) F amplifier.

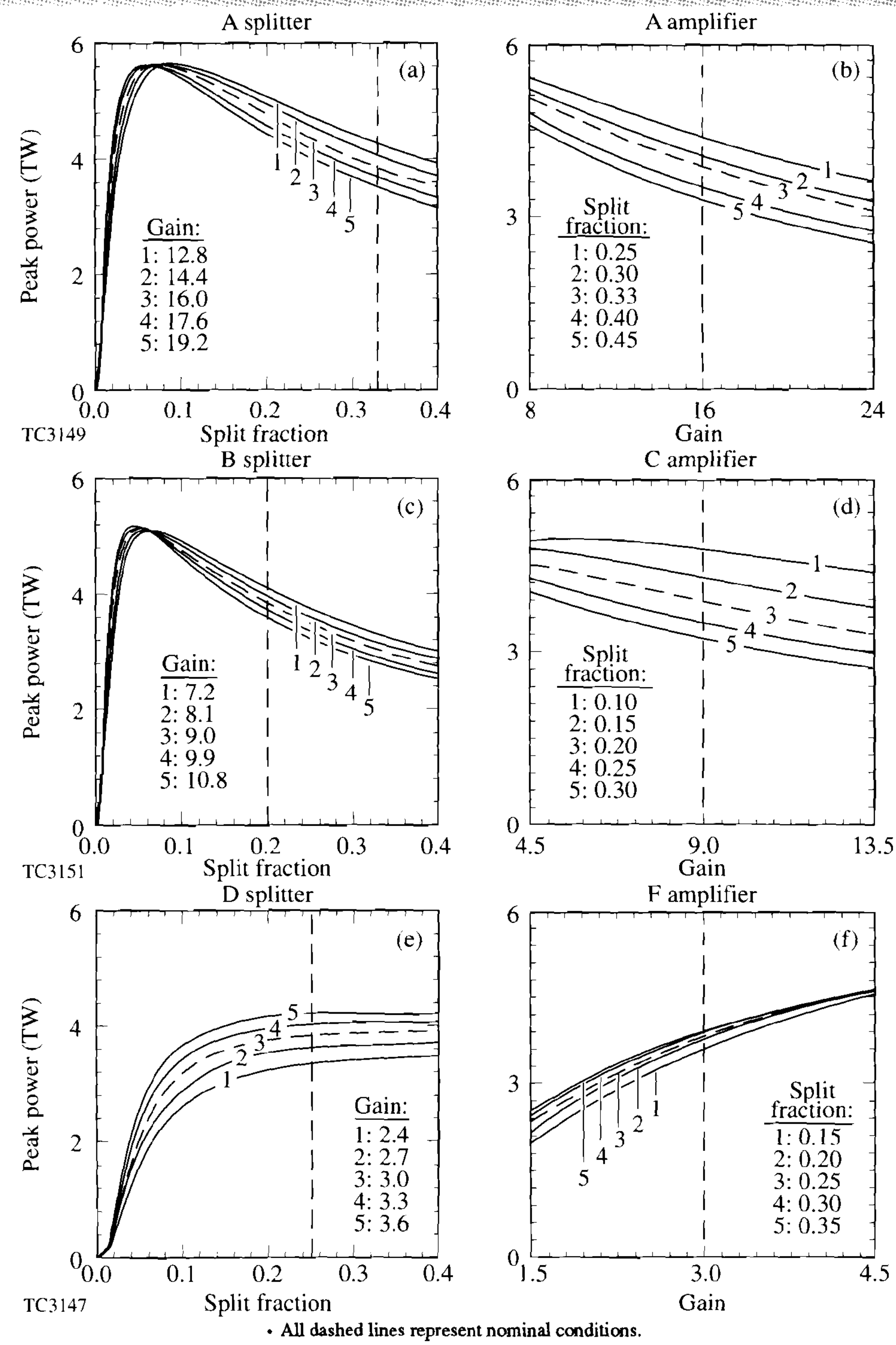

Fig. 52.5
Dependence of the peak UV power for the foot pulse on the amplifier gains and the split fractions. (a) A splitter and (b) A amplifier; (c) B splitter and (d) C amplifier; (e) D splitter and (f) F amplifier.

when split fractions and amplifier gains are increased. In particular, for the case of the D splitter [Fig. 52.5(e)], the peak power is practically independent of the split fraction near the operating condition and thus can only be controlled by varying the amplifier gain. The important point to note in these figures is the lessening of the "leverage" available to vary the output energy and peak power as one moves from the D-splitter group to the A-splitter group, i.e., the slope of the curves becomes flatter. This is especially evident when the dependence of the output energy on the amplifier gains is compared for each amplifier: for the A and C amplifiers [Figs. 52.4(b) and 52.4(d)] the output energy is almost independent of the gain, which means that the gain of these two amplifiers cannot be used to correct any output-energy imbalance between clusters of four beams for the D amplifier and clusters of 15 beams for the A amplifier. On the other hand, this low sensitivity increases the tolerance for the precise tuning of the amplifier gains in the first three stages of the laser. Finally, Figs. 52.4 and 52.5 show that the dependence of the output energy and peak power on the split fractions and amplifer gains is nearly linear in most cases near the operating points so that the linear relationships in Eq. (2) can be used in the analysis.

This lack of leverage means that any method that includes tuning the components in the A and B groups cannot improve much on results obtained with only the D group. In the method by which the individual clusters in the D group are first balanced, followed by balancing the B and A clusters, no values of the splitter fractions and amplifier gains in the A group could be found to reduce the power imbalance to the desired values. The method by which the entire system of 139 equations is solved does provide a solution, but the method tends to favor energy balance rather than peak-power balance. This probably results from the inability to tune the splitters and the amplifier gains in the A and B groups to provide both energy and peak-power balance. Finally, iterative methods, such as first balancing the energy and then the peak power, were found to require too many iterations; hence, too many full-power shots to converge.

The method proposed in this article balances the beam power by varying the split fractions in the 15 D splitters and the gain of the 60 F amplifiers. The measured quantities are the output energy and the peak power for each beam. This scheme works because the splitter fraction controls the power early in the pulse, while the amplifier gain controls the power late in the pulse. Not all the constants in Eq. (2) need to be obtained. Model results indicate that the value of these constants does not differ appreciably from beam to beam and that power balance is obtained as efficiently with four constants as with the entire set. Eq. (2) thus reduces to

$$\Delta E_j = a_1 \, \Delta F_j + a_2 \, \Delta G_j$$

$$\Delta P_j = b_1 \, \Delta F_j + b_2 \, \Delta G_j \quad , \tag{4}$$

where ΔF_j is now the D-splitter fraction and ΔG_j is the F-amplifier gain for beam j. Only two beams (in one cluster) need to be fired to obtain the four constants in Eq. (4). With one beam, a_1 and b_1 are obtained by varying one of the D-splitter fractions, keeping the gain constant, and measuring the total energy and the peak power. With the second beam, a_2 and b_2 are obtained by varying the F-amplifier gain, keeping the splitter fraction constant, and measuring the same quantities. A full-power shot with all beams is still required to obtain baseline measurements of the output energy and peak power in order to balance all the beams.

The beams are balanced by finding the values of ΔF_j and ΔG_j in Eq. (4) that are needed to modify the beam outputs by the quantities ΔE_j and ΔP_j, which are the differences between the beam output and a desired average value. For each cluster of four beams, this is obtained by solving the set of linear algebraic equations

$$
\begin{aligned}
&a_1\,\Delta F_1 + a_2\,\Delta G_1 = E_{\mathrm{av}} - E_1\\
&a_1\,\Delta F_2 + a_2\,\Delta G_2 = E_{\mathrm{av}} - E_2\\
&a_1\,\Delta F_3 + a_2\,\Delta G_3 = E_{\mathrm{av}} - E_3\\
&a_1\,\Delta F_4 + a_2\,\Delta G_4 = E_{\mathrm{av}} - E_4\\[1ex]
&b_1\,\Delta F_1 + b_2\,\Delta G_1 = P_{\mathrm{av}} - P_1\\
&b_1\,\Delta F_2 + b_2\,\Delta G_2 = P_{\mathrm{av}} - P_2\\
&b_1\,\Delta F_3 + b_2\,\Delta G_3 = P_{\mathrm{av}} - P_3\\
&b_1\,\Delta F_4 + b_2\,\Delta G_4 = P_{\mathrm{av}} - P_4\\[1ex]
&\Delta F_1 + \Delta F_2 + \Delta F_3 + \Delta F_4 = 0\ ,
\end{aligned}
\tag{5}
$$

where E_{av} and P_{av} are the desired average output energy and peak power per beam and E_j and $P_j\,(j = 1,4)$ are the output energy and peak power for each beam. The last expression is another way to state the requirement that the sum of the split fractions be unity, assuming that it was initially unity. For the 15 clusters we now have 135 equations (60 for the energy balance, 60 for the power balance, and 15 for the split-fraction sums), and 122 unknowns (120 unknown values of ΔF and ΔG, and the two unknown quantities E_{av} and P_{av}). Thus the system of equations is overspecified. If each cluster were to be solved separately, obtaining different values of E_{av} and P_{av} for each cluster, then we would have 15 well-specified systems of equations per cluster. Energy and peak-power imbalance, however, would remain between the clusters. Attempts to balance these clusters by tuning the A and B splitters and the A and C amplifiers have been unsuccessful because of the lack of "leverage" of the components.

In the method chosen, the last equation is dropped, E_{av} and P_{av} are computed from the beam energies, and peak powers are measured in full-power shots. Since the condition on the sum of the split fractions is relaxed, that sum can now exceed unity. When this occurs, it means that there are no solutions to the system of equations that would result in zero variation in the output power and peak power, while keeping the sum to unity in all the clusters. To maintain the sum of the split fractions as close to unity as possible, so as to keep the loss of laser energy to a minimum, the split fractions are corrected in the following manner.

The largest value from the 15 sums of split fractions (in the 15 D-splitter clusters) is found and all the split fractions are divided by that value. Thus, the sum of the fractions for a single cluster is unity and the sums for the other clusters are slightly less than unity, resulting in a slight loss in laser output energy.

The solution requires several iterations because of the slight nonlinearity in the dependence of the output energy and peak power on the splitter fraction and F-amplifier gain (see Figs. 52.4 and 52.5). Steps for balancing the beams are as follows:

1. An initial full-power shot is taken at nominal conditions. This shot can be the full-power shot required to obtain the constants in Eq. (4).

2. The average energy E_{av} and average peak power P_{av} are computed from the measured energy and peak power of the 60 beams.

3. The following set of 120 equations is solved for ΔF_i and ΔG_i using a conventional method such as Gaussian elimination:

$$a_1 \Delta F_i + a_2 \Delta G_i = E_{av} - E_i$$

$$b_1 \Delta F_i + b_2 \Delta G_i = P_{av} - P_i \qquad i = 1, 60.$$

4. The split fractions are corrected so that the largest sum of the split fraction is unity.

5. The D-splitter fractions and F-amplifier gains are modified by ΔF_i and ΔG_i, respectively, and a full-power shot is taken to check the power balance. At this point an updated value of E_{av} is obtained if needed for the next iteration. (Updating P_{av} results in slightly larger energy and peak-power imbalance for a given iteration step.)

6. If necessary, another iteration is carried out by returning to step 3.

One full-power shot is required per iteration, after the initial full-power shot at nominal conditions and a full-power shot with only four output beams to obtain the constants. For the purpose of this article, a final shot with both the foot pulse and the main pulse was simulated to obtain the rms variations of the output energy, the power at the front of each pulse, and the peak power.

The model was run for a case where all the split fractions, the amplifier gains, and the stage losses were initialized with variations obtained from a series of Gaussian random numbers with $\sigma_{rms} = 0.02$ to simulate the accuracy with which these components can be initially set. Table 52.II shows a sample of the variation percentage of the components in one beamline. The set of variations can be considered to be somewhat pessimistic since several variations exceed 2%. Tight controls during the construction of the laser would probably eliminate any variations above 2%. The initial foot-pulse and main-pulse energies were 82.2 J and 781 J, respectively. A 1% error (also from a Gaussian random-number distribution) was applied to the measurements of the output energy and peak power. A 2% error in the measurements makes it impossible to balance the

Table 52.II: Sample of the applied percent σ_{rms} variations obtained from a Gaussian random-number distribution with σ_{rms} = 0.02.

A group			B group					D group							
$\frac{\Delta F_s}{F_s}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$	$\frac{\Delta F_s}{F_s}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$	$\frac{\Delta F_s}{F_s}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$	$\frac{\Delta L}{L}$	$\frac{\Delta G}{G}$
1.8	-0.59	-3.1	-0.06	-0.37	0.62	0.60	2.9	-1.3	2.6	1.9	0.72	-2.8	-1.5	4.8

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beams. Figure 52.6 shows the asymptotic improvement in the fractional standard deviation (standard deviation divided by the mean) of the output energy (a), the front power (b), and the peak power (c) with the number of iterations for the foot pulse. The standard deviation for the peak power and the energy drops rapidly after five iterations below 10^{-3}, while the standard deviation for the front power does not drop below 0.02 and does not improve beyond the third iteration. The temporal dependence of the fractional standard deviation of the power, at nominal conditions and after three iterations, for both the foot pulse and the main pulse is shown in Fig. 52.7. The deviation is the largest early in the pulse because the gain at that time (the small-signal gain) is larger than the large-signal gain at the end of the pulse. The jump in the deviation at the junction of the foot and main pulses is also caused by the same effect. The deviation at the front of the pulse is the same for both the foot pulse and the main pulse. This is important because the power balance must be as good early in the main pulse as it is during the foot pulse. The final foot-pulse and main-pulse energies are 77 J and 730 J, respectively—a reduction of about 6% for both pulses.

Restrictions on the value of gain of the F amplifier have not yet been considered. The design of that amplifier actually restricts the "head room," or the amount by which the gain can be increased over the nominal gain, to 5% of the nominal gain. In the previous example, the gains of 24 of the 60 amplifiers were larger than 5% nominal, with some gains as high as 30% higher than nominal. Four entire clusters had gains that exceeded the design head room. This problem can be partially remedied by inspecting the beams or clusters that require the large gains and fixing or swapping the components that cause the demand for large gains. Derating the laser energy would, of course, also solve the problem.

The fact that a beam or a cluster requires a larger gain than the others is not necessarily because the input to that beam or the cluster is lower than that of the others. The large gain requirement is caused by the "competition" between the splitter fractions and the amplifier gains. For demonstration purposes, we consider "balancing" a single beam, i.e., computing how much the split fraction ΔF and the amplifier gain ΔG need to be changed so as to remove a given energy and peak-power variation, ΔE and ΔP, respectively. The solution of Eq. (4) for ΔG in the case of a single beam is given by

$$\Delta G = \frac{-a_2 \Delta E + a_1 \Delta P}{a_1 b_2 - a_2 b_1}$$

For a given ΔE and ΔP, ΔG can be either positive or negative. As an example, we consider beam 1 in the solution discussed previously. The constants are $a_1 = 203\ \mathrm{J}^{-1}$, $a_2 = 29\ \mathrm{J}^{-1}$, $b_1 = 1.15\ \mathrm{TW}^{-1}$, and $b_2 = 0.71\ \mathrm{TW}^{-1}$. The energy and peak-power variations from the mean values are $\Delta E = -8.0$ J and $\Delta P = -0.02$ TW. The solution to the system of equations

$$\begin{aligned} 203\ \Delta F + 29\ \Delta G &= -8.0 \\ 1.15\ \Delta F + 0.71\ \Delta G &= -0.02 \end{aligned}$$

is $\Delta F = -0.046$ and $\Delta G = 0.043$. Thus, while balancing the energy requires decreasing the output of beam 1 by 8 J, this is actually done by decreasing the split fraction and *increasing* the amplifier gain. The beam can only be balanced by subtracting large changes in the energy caused by changes in the split fraction and the gain (hence, the term "competing" used previously). The problem arises from balancing the output energy and peak power in the beams simultaneously. Changes in output energy (or in peak power) cannot be "shared" by the two components because a change in ΔF and ΔG that satisfies the needed change in ΔE cannot provide the change that would balance the peak power.

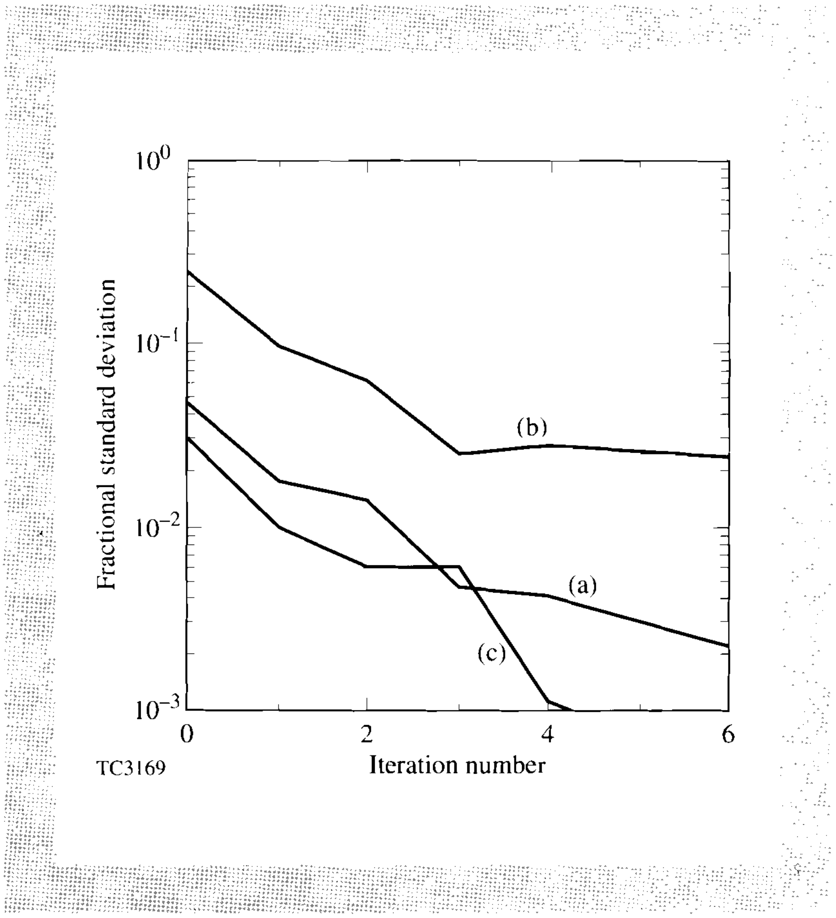

Fig. 52.6
Dependence of the fractional standard deviation on the number of iterations for (a) the output energy; (b) the power at the front of the pulse; (c) the peak power.

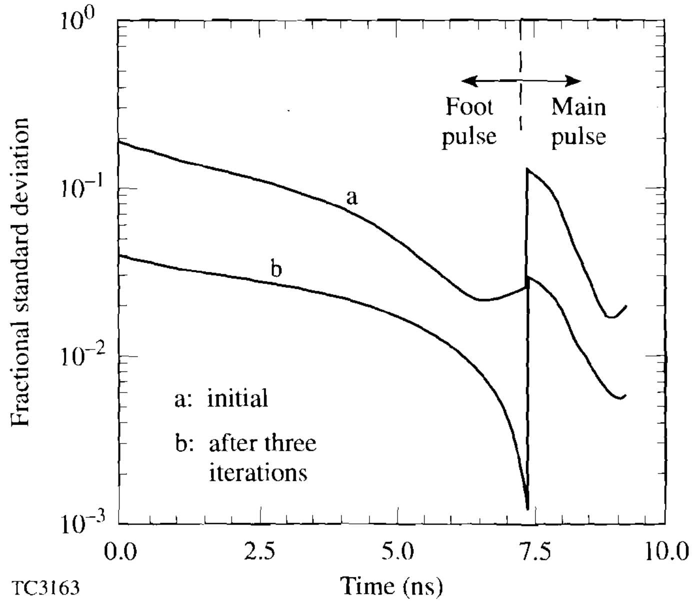

Fig. 52.7
Temporal dependence of the fractional standard deviation for the entire pulse for nominal conditions and after three iterations.

A final topic of interest is the use of a Gaussian pulse, which is easy to produce, to tune the splitter fractions and the F-amplifier gains. Again the tuning is done over a few iterations. Figure 52.8(a) shows the nominal temporal-fractional deviation and the deviation after three iterations for a 1.8-ns Gaussian pulse. The energy balance is about 1%, and the power balance is worse past the peak of the pulse than in the early part of the pulse. The foot pulse in Fig. 52.3 is then propagated through the chain with the splitter fractions and the amplifier gains obtained by tuning the Gaussian pulse. The resulting fractional deviations are plotted in Fig. 52.8(b) as a function of time for the nominal case and after three iterations in the tuning of the Gaussian pulse. The energy balance is now 1.2%, the power balance at the front is 6.6%, and at the peak power is 0.8%. Thus, when a Gaussian pulse is used to tune the splitter fractions and the amplifier gains, the resulting energy and power balance are about a factor of 2 to 3 worse than if the tuning was done with the actual foot pulse in Fig. 52.3.

Conclusions

We have proposed a strategy for balancing the power in the OMEGA Upgrade laser that satisfies the following basic requirements: The power balance at the laser output must be better than 5%; beam measurements can only be done at the laser output; the least number of components should be tuned; and the number of full-power shots should be five or fewer. Also, it was assumed that the split fractions, the amplifier gains, and the losses were known to within a 2% Gaussian random error and that the measurements could be carried out with a 1% error. The method proposed involves measuring the output energy and the peak power, and tuning the D-splitter fractions and the F-amplifer gains. The tuning, which can be carried out with a minimum of three full-power, 60-beam shots and one full-power, two-beam shot, provides a power balance better than 2% over the entire

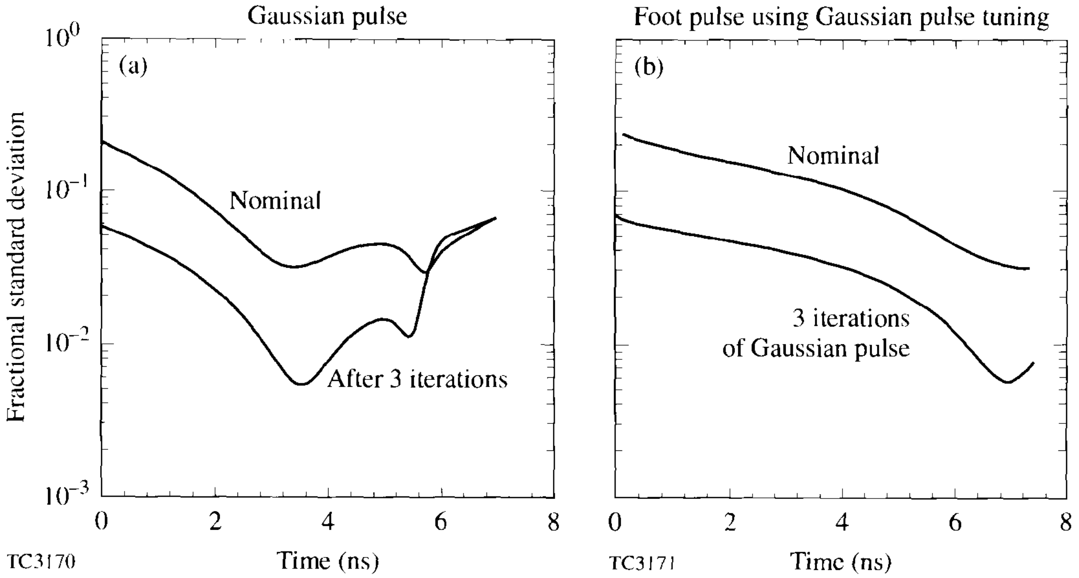

Fig. 52.8
Temporal dependence of the fractional standard deviation when using a Gaussian pulse to obtain the constants in Eq. (2). (a) Gaussian pulse; (b) foot pulse.

foot and main beams. This level of power balance is obtained at the expense of the output beam energy, which is reduced by about 6%. It also requires a 1% measurement accuracy of the UV ouput energy and peak power. The following were not considered in this article: power imbalance caused by uncertainties in the conversion-crystal efficiency, including variations in beam sizes; variations in the transport optics; and beam timing.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under agreement No. DE-FC03-85DP40200 and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics, which is sponsored by the New York State Energy Research and Development Authority and the University of Rochester.

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