The Design of LMJ focal spots for indirect drive experiments

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Abstract. LMJ is a 240 high power laser beam facility for achieving laser matter interaction experiments, high energy density science, including the demonstration of fusion ignition through Inertial Confinement. The Laser Integration Line (LIL) facility is currently a 4-beam prototype for LMJ. The intensity I₀ at the focal spot centre drives hydrodynamic and plasma instabilities and the intensity in the wings must be low to go through the laser entrance Hohlraum. A simple model has been developed to compute the LMJ focal spot. The model gives the intensity at the centre as a function of the focal spot area at 3% of the maximum.

1. Introduction

The Laser Integration Line (LIL) facility is currently a 4-beam prototype for LMJ. The purpose of LIL and of these experiments is to show that the previously untested features of the LMJ laser design will perform as projected at LMJ scale and that the laser is therefore ready for final engineering design. LIL Quad beam waist was recorded for various pulse durations, smoothing techniques and for a wide range of laser intensities up to LMJ-nominal ones [1]. Now, LIL quad has been commissioned to the center of the target chamber and the first plasma experiments are being made.

LMJ focal spot requirements are: elliptic shape, almost flat top high-order super-gaussian envelope, spot size, intensity at the center. In fact, it is important to know precisely the intensity I₀ at the focal spot center (to control hydrodynamic and plasma instabilities) and the intensity at the edges of the focal spot (to go through the laser entrance Hohlraum). For LMJ focal spots, it has been decided that this level will be 3 % of I₀.

2. Basic principle of the focal spot design

The LIL laser baseline can be restricted to 3 main sections or subsystems:

- the front end that delivers and controls input energy, temporal pulse, and generates the initial near field (square of 4cm width) and the 140 GHz spectral bandwidth for smoothing [2].
- the main amplifier section made of two amplifiers with 9 laser glass slabs each in a 4-pass layout.
- the final optic assembly (see figure 1) where both frequency conversion and focusing take place. The first component is the 1₀ grating. An angular dispersion of the spectrum is induced by the grating which allows broadband frequency tripling and time delay pre compensation. The frequency converters use a Type I-Type II third harmonic generation scheme, consisting of a 12.5-mm-thick KDP doubler crystal and a 9-mm-thick DKDP tripler crystal. Finally, the 3₀ grating focuses the beam onto the target through the vacuum window, the continuous phase plate [2] devoted to beam smoothing/shaping and the debris shield.
Beam smoothing is obtained by the longitudinal chromatism introduced by the focusing grating. The result on target is the superposition of many beamlets having different colors and producing smooth time-averaged interference patterns. The continuous phase plate (CPP) creates diffraction limited spots inside the far field pattern (speckle pattern see figure 3). Nevertheless, there is a slight transverse effect because each grating is off axis. This effect is enhanced when the four beams are overlapped (see figure 2).

**Figure 1.** Final Optics Assembly as mounted on LIL target chamber including focal spot diagnostics

**Figure 2.** Quad Focusing geometry and grating-induced chromatism.

**Figure 3.** Typical speckle pattern inside the focal spot obtained with a continuous phase plate

### 3. LIL focal spot results

The LIL focal spot has been carefully recorded during the commissioning campaign and details of the focal spot diagnostics can be found in [1, 3]. The reference profile for the quad focal spot is taken from the 5 shot recording shown in figure 4. The smooth envelope is due to three effects: phase
modulation is turned on and all four beams have CPP; beam overlap is carefully synchronized; CCD resolution.

Figure 4. LIL quad focal spot: 5 shots are overlapped (energy 2.5 to 4.8 kJ, pulse duration 0.7 to 5 ns)

Figure 5. Normalized intensity of the LIL quad focal spot without CPP and 14 GHz. Upper dotted curve is a single beam focal spot profile and the lower one is the quad. The plain curve is a Lorentzian fit

It is possible to remove the phase plate and turn off the phase modulation at the front-end to measure the laser beam aberrations of a single beam line. The normalized intensity profiles are best fit with a Lorentzian function as shown figure 5. In this example, noise ranges from 2 \(10^{-3}\) to 5 \(10^{-3}\) and it can be seen that the Lorentzian function fits accurately even in the wings of the spot below 1%.

At the same time, the continuous phase plate far field is measured with an optical set-up [4]. Its intensity impulse response is a super gaussian function. So far, it is possible to calculate the far field envelope.

4. LMJ focal spot

Let us define \(f(x,y)\) and \(g(x,y)\) respectively the amplitude response functions of the LIL and of the phase plate:

\[
f(x,y) = 1/[1+(r/r_l)^2] \text{ with } r = \sqrt{x^2 + y^2}
g(x,y) = \text{Exp}[-(x/r_{xp})^{np} - (y/r_{yp})^{np}]
\]

\(x, y\) being the coordinates in the far field plane, \(r_l\) the half width at half maximum of the Lorentzian function, \(r_{xp}\) and \(r_{yp}\) the half widths at \(1/e\) of the supergaussian function along \(x\) and \(y\).

The far field intensity is defined as:

\[
I(x,y) = I_0 \int_{-\infty}^{\infty} f(t,x,u) g(t-x, u-y) dt du
\]

Where “⊗” stands for the convolution product.

At first, this calculation is applied to the LIL case and the result is compared with the focal spot recorded as shown on figure 4. From the Lorentzian fit of the figure 5, \(r_l = 80 \mu m\) and from the phase plate measurements, \(r_{xp} = r_{yp} = 240 \mu m\) when \(np = 4\).

The calculation of LMJ focal spot is based on the following assumptions:

- laser beam aberrations as measured on LIL
- phase plate far field as a function of eccentricity, width (0.2 to 1.2 mm) and super-gaussian order (1, 2, 4).
The results of the calculation are: the normalized intensity at the focal spot center and the area of the focal spot defined at 3% of the maximum.

Therefore, it is possible to calculate the intensity as a function of the focal spot area. It is straightforward to define the equivalent pulse duration ($d_{eq}$) as $d_{eq}=E/P$ and the focal spot equivalent surface ($S_{eq}$) as $S_{eq}=P/I_0$ and to show that:

$$P = E / d_{eq} = \int I(x,y) dxdy = I_0 S_{eq}$$

An example is shown figure 7 in the case of a phase plate with $r_{xp} = 100, 200, 300 \mu m$, $r_{yp} = 400, 500, 600 \mu m$ and $n_p = 4$. Quad energy is 2 MJ/60= 33.33 kJ and $d_{eq}= 3.7$ ns. The best fit gives the simple result: $I_{14} (10^{14} W/cm^2) = 27.65 S_{2\pi n_p^{-1.2728}} (mm^2)$

**Figure 6.** Recorded LIL quad focal spot (dotted curve) compared to calculation (plain curve). See text for details.

**Figure 7.** Intensity at the quad focal spot centre ($I_0$) as a function of the focal spot area. Dots are the results of the calculations and the dotted line is the best fit (see text).

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### 5. Conclusion

From the focal spot measurements recorded on the LIL facility, it is possible to calculate the focal spot of the LMJ for any phase plate order, eccentricity and width. An analytical function is found to evaluate the intensity at the focal spot centre. The model gives the intensity at the centre as a function of the focal spot area at 3% of the maximum.

### References

[1] Di-Nicola J et al 2006 J. Phys. IV France 133 595
[2] Jolly A, Gleyze J, Luce J, Coic H and Deschaseaux G 2003 Opt. Eng. 42 1427
[3] Le Garrec B, Di-Nicola J, Beau V and Julien X 2006 J. Phys. IV France 138 297
[4] Neauport J, Ribeyre X, Daurios J, Valla D, Lavergne M, Beau V and Videau L 2003 Appl. Opt. 42 2377