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Parasitic pencil beams caused by lens reflections in laser amplifier chains

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ABSTRACT

Reflections from lens surfaces create parasitic beams that can damage optics in high-powered laser systems. These parasitic beams are low in energy initially, because of the low reflectivity of antireflection (AR) coated lens surfaces and because they are clipped by spatial filter pinholes, but subsequent amplification can raise them to damage fluence levels. Also, some of the pencil beams in multipass laser systems become pre-pulses at the output by by-pass one of more of the passes, arriving at the output ahead of the main pulse in time. They are insidious because pencil beams that are not initially a problem can become so due to a slow degradation of the AR coatings. Both the Nova and Beamlet¹ laser systems at LLNL have had optics damaged by pencil beams. The best solution for pencil beams is to tip the lenses far enough to eliminate them altogether². This will be the approach taken for the National Ignition Facility³ (NIF).

1. PENCIL BEAM FORMATION

Pencil beams are formed from back reflections that are clipped by spatial filter (SF) pinholes. Figure 1 shows the two pencil beams formed from the output lens of a (SF).

Figure 1 Pencil beam formation from the two surface reflections of a lens.

The reflections from both surfaces diverge toward the pinhole, which transmits a beam of the diameter of the pinhole, typically a few millimeters. The lens surface away from the pinhole, i.e., the air-surface of a vacuum SF (S1 in Fig.1), couples more energy through the pinhole, because its focus is closer to the pinhole. Reflections from the next down-beam lens, e.g., the input lens of the next SF, also form pencil beams, and the lens surface closest to the pencil-beam-forming pinhole, again the air-surface for a vacuum spatial filter, couples the most energy through the pinhole. In this case the image of the ghost focus from that surface is closer to the the pinhole.

2. GENERAL PROPERTIES

The size variation of a pencil beam as it propagates through a laser system depends on the details of the optical layout. In the case of the Beamlet laser system, pencil beams remain small throughout the laser, thus the name "pencil beam". The Beamlet laser has the off-axis, multipass, relayed optical layout shown schematically in Fig. 2. The initial pulse is injected into the cavity SF (CSF) near the pinhole plane and makes four passes through the cavity amplifier (amp1) before

Figure 2 Schematic of the optical layout for Beamlet. Only beam centerlines are shown and the transverse offsets between passes are exaggerated for clarity. (Real offsets are ± 1.5 cm at the pinhole plane for a 35 cm aperture beam).

being re-directed to the booster amplifier (amp2) and transport SF (TSF) by the plasma electrode Pockels cell (PEPC) and polarizer (pol). A typical pencil beam for the Beamlet laser, is shown in Fig. 3. It starts from the air-side reflection off L2 of the CSF and is clipped to a diameter of 3.6 mm at the pinhole. It expands to 5.1 mm at lens L1 and converges to 4.3 mm after propagating the 26 m to the cavity mirror (M1) and back to L1. For Beamlet, this 26 m propagation distance is the largest propagation distance for the collimated beam. Since the system is fully relayed, all beam

Figure 3 Beam sizes for a typical Beamlet pencil beam.

sizes in the other collimated sections are represented in this distance. The smallest size of this pencil beam, about 2 mm, occurs in the vacuum region of the SF. Pencil beams are also typically diffraction limited, because of the distance of the ghost focus from the defining pinhole. For the reflected light coming through the pinhole in the example of Fig. 3, the diffraction limited source diameter is $2.44lf/D = 4.4$ mm, where l is wavelength, f is the radius of curvature of the reflected light at the pinhole (6.21 m), and D is the pinhole diameter. Since 4.4 mm is larger than the 3.6 mm diameter of the pinhole and larger than the ghost focus, all the light coming through the pinhole from the ghost focus is diffraction limited.

3. BEAMLET PENCIL BEAMS

Multipass systems like Beamlet and NIF create a great number of pencil beams. Each SF has several pinholes, and each exposed pinhole creates two pencil beams (one for each lens surface) on each pass through the SF. For the Beamlet architecture, the injected pulse makes four passes through the cavity SF before making its final pass through the transport SF, as shown in Fig. 2. Furthermore, each reflection from the polarizer splits one pencil beam into two. The result is more than 100 pencil beams for the Beamlet architecture.

Most Beamlet pencil beams are inconsequential, because they do not see enough gain to reach significant fluence levels. However, a few which return to the injection optics are potentially serious if the reflectivity of an AR coating increases. Figure 4 shows data from a diagnostic monitoring the back-reflected energy at the front-end of Beamlet for a shot that delivered 5.5 kJ output at 1w. It shows relative back-reflected energy as a function of time. Individual pencil

Figure 4 Back reflected pulses measured at the front end of Beamlet.

beams are identifiable because of their different time delays. The first pencil beam in Fig. 4, L2,2, came from the reflection off lens L2 on pass 2. (See Fig. 2). It was formed on pinhole 2, passed backwards along passes 2 and 1 (getting amplified by amp1 twice), and back through pinhole 1 to the injection optics. The second pencil beam, L1,4, was produced similarly from L1 on pass 4. In this case the entire reflection went twice through amp1 and formed the pencil beam on pinhole 1 just before entering the injection optics. L2,4 and L3,4 were formed on pinhole 2 and propagated to the front-end exactly as L2,2. Note that the latter three pencil beams, which started from reflections on pass 4, effectively by-pass the isolation by jumping to pinhole one or two in the CSF.

Evidently the L2,4 pencil beam was the most energetic in this case. For equal AR coatings, we expect the pencil beams from the air-side of L3 to be more energetic than those from L2, because they couple the same energy through the pinholes but see two more passes through the booster amplifier. Since L2,4 was larger than L3,4, we conclude that the AR coating on L2 had a significantly higher reflectivity than that of L3.

The focal properties of a pencil beam also influences its damage threat to optics. Beamlet pencil beams do not change in size very much throughout the collimated section of the laser, and, as a result, none of them threaten the full aperture optics. However, a few do focus significantly in the vacuum sections of the spatial filters, and these can threaten the injection optics. The pencil beam from L2 shown in Fig. 3 diverges from an effective focal size of about 2 mm, and this minimum spot size is re-imaged inside the SF on subsequent passes. Although, this particular pencil beam does not re-image near the injection optics, one of the pencil beams from L3 does.

The pencil beam which creates the highest fluences at the injection optics results from the air-side reflection off L3 on pass 4, assuming equal AR coating reflectivities. Figure 5 shows diffraction calculations of this pencil beam profile (relative fluence versus position) at a) the injection mirror and at b) the injection lens. It shows the pencil beam approaching its minimum

Figure 5 Calculated pencil beam profiles from L3 at a) the injection mirror and b) the injection lens.

diameter at the injection lens. The calculation assumes a reflected amplitude of unity at the lens, and does not include amplification. Consequently, Fig. 5 shows that a reflection of 1 J/cm^2 from L3 would result in a peak pencil beam fluence at the injection mirror of 0.8 J/cm^2 times the intervening amplification. (Note that the calculation shows the injection optics are in the near field of the image of the pinhole which formed the pencil beam. As a result, the on-axis peak-to-average intensity fluctuates by 4:1 depending on the exact position of the optic.)

Figure 6 shows calculated average fluence for this pencil beam at the injection lens as a function of Beamlet output energy. It assumes the relative fluence shown in Fig. 5 and three

Figure 6 Calculated average fluence from the L3 pencil beam at the injection lens as a function of Beamlet output energy at 1w, for three values of AR coating reflectivity.

different values for AR coating reflectivities. Note that the pencil beam fluence drops for the highest Beamlet outputs, because the amplifiers are substantially saturated by the out-going pulse, leaving relatively little gain for the back-reflected pencil beam. Consequently, the highest fluence pencil beams result for Beamlet outputs between 3 and 5 kJ.

A major conclusion to be drawn from Fig. 6 is that Beamlet is very safe against the worst pencil beams for reasonably good AR coatings, i.e., reflectivity $\leq .005$. In that case, the highest average fluence would be about 3 J/cm^2 , adequately below typical damage fluences for these optics ($\sim 15 \text{ J/cm}^2$) to allow for peak-to-averages as large as 4 without damaging. However, a degraded coating which approaches the reflectivity of an uncoated surface (.034 for fused silica) could easily damage these optics. In fact, the injection optics on Beamlet have been damaged by this pencil beam on a shot which delivered only about 800 J, because the AR coating on the air-side of L3 had degraded to a reflectivity of .031.

4. ELIMINATING PENCIL BEAMS

There are at least three ways to attenuate or eliminate pencil beams: tilting the lenses, increasing isolation, and blocking the pencil beams in the near field of the beam. None is cost-free or free of undesirable side effects, but we strongly prefer the lens-tilting solution. Tilting lenses³ can entirely eliminate pencil beams, if they can be tilted enough to move the ghost foci outside the beam aperture. The required tilt decreases with lens F#, but it is more than two degrees even for the relatively large F#'s of Beamlet lenses (F/22). Although this much tilt would introduce too much beam aberration for normally figured lens, the lenses can be specially figured to adequately reduce aberrations³.

The second possibility is to redistribute or add isolation to attenuate pencil beams. An example of an alternative architecture which would potentially improve isolation against pencil beams is presented elsewhere. However, architectural changes are relatively drastic and influence overall system performance in many ways. They are unattractive because they would require extensive re-optimization of the system design and would likely lead to compromises in performance criteria.

The third possibility is to physically block the pencil beams at a relay plane. A single pencil beam could be blocked with a small ($< 1 \text{ cm}$ diam) absorbing-glass beam dump, attached to one of the cavity mirrors. Even with apodization to control edge diffraction, the loss of beam area (and therefore output energy) would be minimal ($< 0.5\%$). However, a diagnostic to monitor the pencil beams and a capability to orient each lens to put the pencil beam on its beam block would have to be included in the system design. Also, several blocks would be required to stop all the potentially damaging pencil beams.

Of these alternatives, we strongly prefer the tilted-lens approach. Although it will likely increase the cost of the lenses slightly because of the special figuring required, it totally eliminates all pencil beams, and it doesn't otherwise effect the system. We plan to test it on Beamlet and to implement it on NIF.

5. SUMMARY

Pencil beams are potentially problematic, because they produce pre-pulses at the system output, and they can subject beam line optics to damaging fluences. They are also insidious, because initially safe pencil beams can become dangerous as AR coatings degrade. Of the several techniques for minimizing the threat from pencil beams, we prefer the tilted-lens approach.

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7. REFERENCES

1. B. M. Van Wonterghem, J. A. Caird, C. E. Barker, J. H. Campbell, J. R. Murray, D. R. Speck, "Recent results of the National Ignition Facility Beamlet demonstration project", *Solid-State Lasers for Application to Inertial Confinement Fusion (ICF)*, SPIE proceedings series, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1995.
2. L. G. Seppala, R. E. English Jr., "The use of tilted spatial filter lenses to solve ghost focus problems in a multi-pass cavity", *Solid-State Lasers for Application to Inertial Confinement Fusion (ICF)*, SPIE proceedings series, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1995.
3. J. A. Paisner, "Conceptual design of the National Ignition Facility", *Solid-State Lasers for Application to Inertial Confinement Fusion (ICF)*, SPIE proceedings series, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1995.
4. S. Seznec, C. S. Vann, F. Laniesse, J. E. Murray, H. G. Patton, B. M. Van Wonterghem, "Testing a new laser architecture concept on Beamlet", *Solid-State Lasers for Application to Inertial Confinement Fusion (ICF)*, SPIE proceedings series, Society of Photo-Optical Instrumentation Engineers, Bellingham, 1995.