Study of the Prompt Aberrations of the Vulcan TAP Beamline

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Abstract

In this paper, we will discuss the progress we have made in addressing the on-shot aberrations that occur when the Vulcan laser is fired, primarily addressing the amount of defocus. We see that there is evidence that the time since the last laser shot plays a significant role in the variability of this parameter, and report our investigation into its temporal evolution. Results shows that it is crucial for there to be a minimal amount of time between running the adaptive optic and then firing the laser.

1 Introduction

The intensity of the focus of the Vulcan laser is often a key parameter for the successful outcome of any experimental campaign conducted on the Facility, and is determined by the pulse energy, duration and focal spot size. Changes to any of these parameters will lead to variation of the focal intensity. Measurement of the pulse energy is relatively trivial using thermo electric heads (Vulcan typically uses Gentec QE 50s), and the pulse duration can be determined using an autocorrelator; however, measurement of the focal spot quality at full energy at focus remains difficult. Recently, we have been using a wavefront sensor to measure the spatial phase of the fired laser pulse and comparing this to the original alignment CW beam and, in this way, making a proxy measurement of the focal spot size on the shot.

An example of the spread in the defocus values recorded during an experimental campaign is shown in Figure 1. As can be seen, the greatest spread occurs when the laser is fired most rapidly. The data shows that there is an impact on the on-shot defocus measurement when beam 7 is fired to TAW, which uses some of the TAP beamline amplifiers. In this paper, we explore the reason behind this and propose a compensation technique.

When the flashlamps are fired to excite the Nd ions in the laser glass, a large amount of heat is deposited into the glass which leads to a non-uniform optical path difference (OPD). Warping of the laser slab (non-uniform expansion), and changes to the glass refractive index brought about by temperature and stress within the glass also contribute to the OPD. This non-uniform OPD can cause the glass to act as a highly aberrated lens that distorts the laser beam as it propagates through the amplifier [1]. As these deformations can occur during the pumping cycle, they are present during the amplification process. However, the on-shot pump induced defocus tends to have the opposite sign to that caused by the non-uniform temperature distribution in the amplifiers as they cool after the shot.

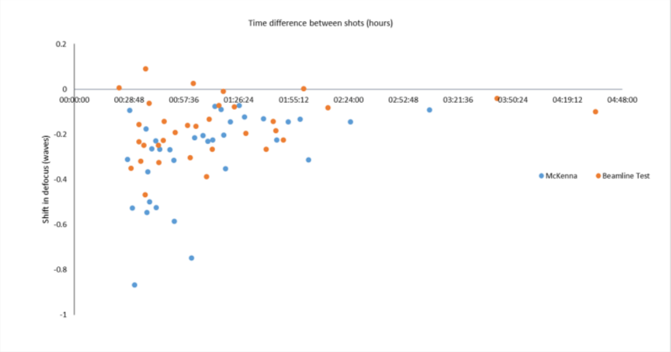

Figure 1: Variation of defocus value against time since last laser shot

2 Vulcan TAP Beamline

In this section, we discuss the relevant sections of the Vulcan TAP beamline. A schematic for the short pulse beam line for TAP is shown in Figure 2. Here we summarise the pertinent points for our discussion: for a detailed description of the beamline see Musgrave et al.[2]

The seed pulse is generated by a commercial Ti:Sapphire oscillator, the output of which is directed to a single stage of ps optical parametric chirped pulse amplification (OPCPA) where it is amplified to 100 μJ. The pulses are then stretched to 4.5 ns in a double decker Öffner stretcher. Following this are three further stages of OPCPA to achieve >60 mJ of energy. These pulses are then amplified in a mixed silicate and phosphate glass rod amplifier chain, before final amplification in a phosphate disc chain. The disc amplifier chain comprises a double pass 108 mm amplifier that has an adaptive optic (AO) as the retro mirror. There then follows a single 150 mm amplifier and three 208 mm amplifiers. There are wavefront sensors in the diagnostic channels at this point, one that provides feedback for the AO optimisation loop and another that measures the on-shot wavefront. The pulses are finally compressed before being directed to the target using an off-axis parabola. A telescope can be inserted into the beam to compensate for the on-shot defocus. This telescope is located after the 25 to 45 mm expanding telescope and the 45 mm amplifier, and is injected using a mirror mounted on pneumatic stages. In the current procedure for operating TAP, the adaptive optics run to correct any residual thermal and static aberrations, and the compensating telescope is inserted to pre-compensate for the on-shot defocus term.

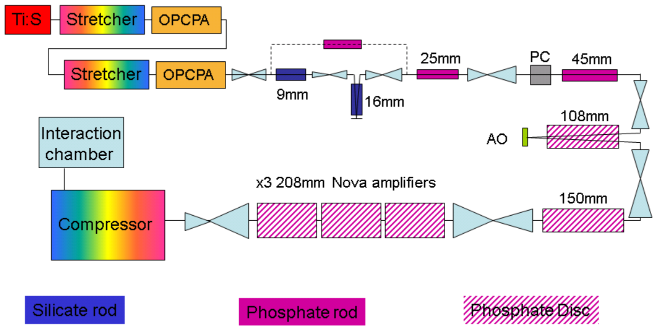

Figure 2: Schematic of the Vulcan beam line for TAP

3 Temporal Evolution of the Defocus term

The data shown in Figure 1 suggests that the time between shots has a major impact on the on-shot defocus measurement. Previous studies [3] have shown that after 20 minutes the aberrations of individual amplifiers have reduced to a sufficient level that the AO can correct any wavefront errors. To understand the long-term temporal evolution of the defocus term, a series of shots was taken of the laser system. After the system was fired, a CW alignment beam was propagated through the laser system onto a wavefront sensor. The defocus was then recorded for up to two hours: an example trace is shown in Figure 3. Figure 3 also shows exponential fits to the rising and trailing edges of the defocus curve given by Equation 1 below.

$$\begin{aligned} D &= A1 + A2\exp\left(-\left(\frac{t - T3}{T1}\right)^2\right) \quad for\ t < T3 \\ &= A1 + A2\exp\left(-\left(\frac{t - T3}{T2}\right)^2\right) \quad for\ t > T3 \end{aligned} \tag{1}$$

A1 is measure of the compensation that is required by a correcting telescope in the system, and A2 is a measure of the 'heat' that has been put into the system. T1 and T2 are measures of the rise and fall times, and T3 is the time of the peak of the defocus term. Equation 1 was used to analyse the defocus decay for a series of shots taken of the whole system. It was found that the average values for A1 and A2 were -0.6 and 0.6 waves respectively, while the average values for T1, T2 and T3 were 15 minutes, 40 minutes and 20 minutes respectively. These results and the curve shown in Figure 3 demonstrate that timing for the next shot is crucial for reducing the variability of the defocus value, because in the space of 10 minutes the defocus value can change by 0.1λ if the time since the last shot was before the peak of the curve (T3).

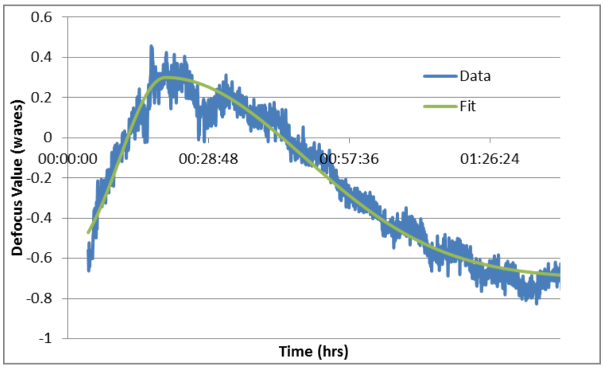

Figure 3: Typical decay of the defocus term with exponential fits

4 Conclusion

In conclusion, it is clear that the timing of the shot sequence is critical for the successful compensation of the on-shot defocus effect introduced when the amplifiers in the laser chain are fired. At present, the AO is run prior to the shot and then a corrective telescope is installed into the chain to apply a correction for the shot. It is clear that the timing between the stopping of the AO and the firing of the laser shot needs to be minimised.

References

[1] Rotter M.D. et al., *"Pump-induced wavefront distortion in prototypical NIF/LMJ amplifiers: modeling and comparison with experiments"*, Pro. SPIE 3492 (1999).

[2] Musgrave I., Shaikh W., Galimberti M., Boyle A., Hernandez- Gomez C., Lancaster K., Heathcote R., *"Picosecond optical parametric chirped pulse amplifier as a preamplifier to generate high-energy seed pulses for contrast enhancement"*, Applied Optics, 49, 6558 (2010)

[3] Hernandez-Gomez C., Collier J.L., Hawkes S.J., Danson C.N., Edwards C.B., Pepler D.A, Ross I.N, Winstone T.B., *"Wave-front control of a large-aperture laser system by use of a static phase corrector"*, Applied Optics, 39, 1954 (2000)