Pump induced aberration characterization and compensation for the Vulcan Petawatt beam

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Introduction

During the September/October experiment in the Vulcan Petawatt facility, the reproducibility of experimental results from previous experiments indicated that the intensity on target was an order of magnitude lower. This apparent change in intensity followed an extensive maintenance period during which a number of changes had been made to the laser system. However only three laser parameters affect the on target intensity; pulse energy, pulse duration and focal spot quality. The Vulcan calorimeters were calibrated and were seen to be reading the correct energy. The auto-correlators in the Petawatt diagnostics area were calibrated and again were reading correctly, within tolerances. This left the focal spot quality as being the only unknown. At the time of this experiment no full shot measurements of the focal spot quality were available and as intensity would be reduced quadratically with the spot size a thorough investigation to the wavefront quality was conducted.

Results

Using a radial sheer interferometer[1], measurements were made of the wavefront quality of the beam leaving the Vulcan disc amplifier chain. In CW mode the wavefront leaving Vulcan was found to be around 0.4 waves Peak-to-Valley (P-V), with a Strehl ratio of 0.86, after the Adaptive Optics (AO) had been run, see Figure 1. When interpreting interference fringes any deviations from straight fringes indicate wavefront distortions.

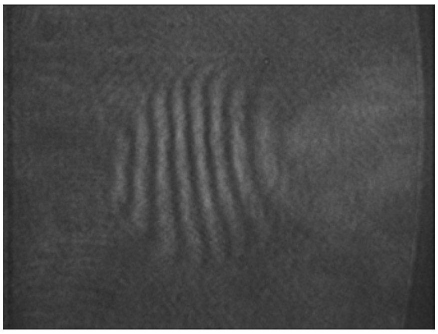


Figure 1. Vulcan CW interferogram with AO run.

This is considered to be in the nominal operating range for the Vulcan Petawatt beam. However when the wavefront of a rod shot was diagnosed it was found to have a significant amount of aberration, as can be seen in Figure 2.

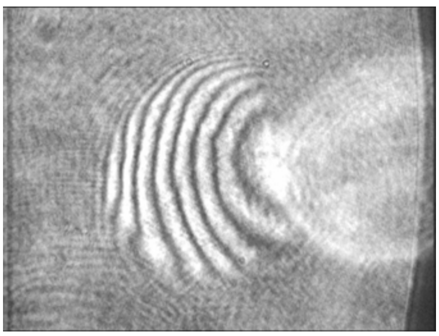


Figure 2. Vulcan rod shot interferogram with AO run.

It is important to note that a previous study of the shot wavefront on Vulcan had been conducted and had found there was no significant change in beam quality from that of the CW mode. However this was conducted prior to the extensive maintenance period. A summary of the wavefront aberrations and significant Zernike coefficients[2] is presented in Figure 3. It is apparent from the Zernike analysis and the curvature of the fringes that the most significant on the shot aberration is that of defocus.

Mode	P-V (λ)	Strehl Ratio	Zernike 4 Astigmatism 45°	Zernike 5 Defocus	Zernike 6 Astigmatism 90°
LA4 CW YLF	0.375	0.910	-3.56E-3	-4.65E-3	-2.65E-3
Silicate CW YLF AO run for silicate	0.508	0.860	-9.62E-2	+1.97E-2	-6.10E-3
OPCPA 9 sec Cycle	0.378	0.836	-1.29E-1	-6.87E-4	-5.86E-2

Figure 3. Summary of wavefront aberrations and Zernike terms.

Further analysis of the aberration was made by subtracting the phase front of that of the CW beam from that of the Rod shots. Upon doing this it became apparent that the shot aberration was largely composed of one wave of defocus, see Figure 4.

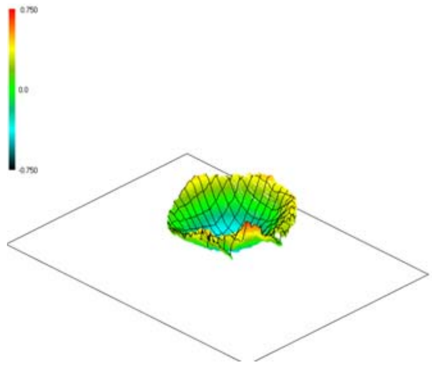


Figure 4. Subtracted phase front of the shot aberration.

It was evident that a significant "on the shot" phenomenon was producing the significant drop in on target intensity. Measurements were made of the rod shot focal spot quality in Laser Area 4, which were in agreement with the heavily distorted interference pattern, see Figure 5.

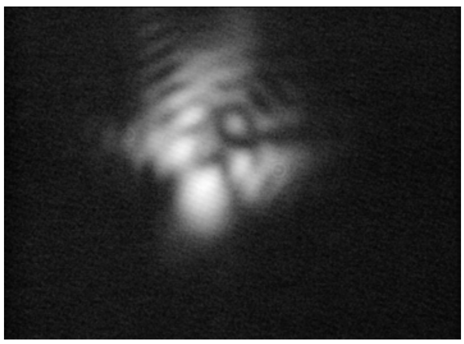
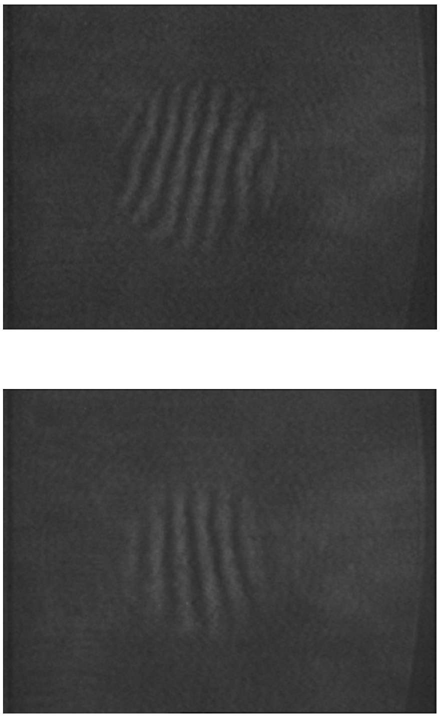


Figure 5. Focal spot at the output of the Vulcan petawatt beam.

Investigation

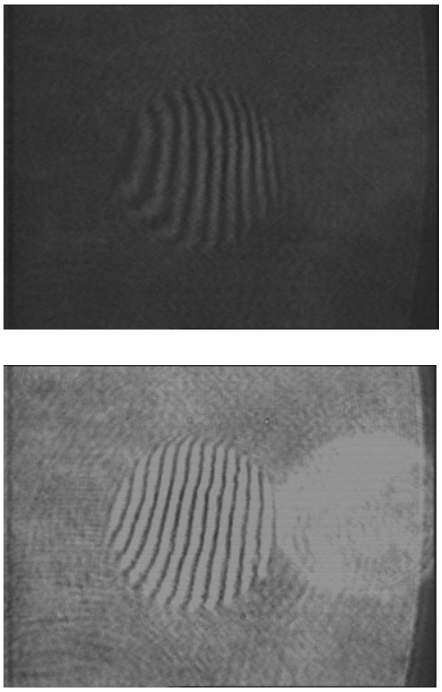
The cause of the shot aberration was not immediately apparent; however a systematic investigation to potential causes was conducted. First it was important to rule out the OPCPA front end which generates the seed pulse for the petawatt beam. Interferograms were recorded with the CW mode and pulsed OPCPA mode and a comparison of the wavefronts made. There appeared to be no significant degradation in beam quality between CW mode and the OPCPA, see Figure 6. This is not unsurprising as the seed pulse is propagated through a diffraction limited pinhole, prior to amplification in Vulcan.



Mode	P-V (λ)	Strehl Ratio	Zernike 4 Astigmatism 45º	Zernike 5 Defocus	Zernike 6 Astigmatism 90º
Silicate CW YLF AO run for silicate	0.508	0.860	-9.62E-2	+1.97E-2	-6.10E-3
OPCPA 9 sec Cycle	0.378	0.836	-1.29E-1	-6.87E-4	-5.86E-2

Figure 6. Vulcan CW (top) and OPCPA interferograms.

Another possible cause for a shot related defocus was the picking up of electrical noise by the adaptive optic. Although noise testing of the Vulcan adaptive optics system was conducted extensively before its deployment on the petawatt beam, the electronics driver unit had been changed recently and could potentially be picking up electrical noise. To test whether the adaptive optic was generating a defocus it was replaced with a static dielectric coated high reflective mirror. A Comparison of the interferograms of the CW beam and rod shots is seen in Figure 7. Without the flat mirror in place a defocus of opposite magnitude to that of the shot aberration was observed, such that when the rod shot was fired a focal shift comparable to that observed before was seen. It is worth noting that as the defocus seen from the flat mirror is of opposite magnitude to that of the shot defocus, some degree and negation takes place. This does however discount the adaptive optic as a potential cause of the defocus as this still occurs with a flat mirror in its place.



Mode	P-V (λ)	Strehl Ratio	Zernike 4 Astigmatism 45º	Zernike 5 Defocus	Zernike 6 Astigmatism 90º
Vulcan CW YLF HR flat	0.910	0.391	-1.75E-1	-2.01E-1	-1.19E-1
OPCPA 2 minute shot HR flat	0.644	0.686	-2.19E-1	-2.12E-2	+1.953E-2

Figure 7. CW and rod shot interferograms from a flat mirror.

The next step in the investigation was to characterize each rod amplifier individually. This would indicate whether a single rod amplifier was causing the defocus. Figure 8 shows a comparison of the wavefront aberrations observed from the individual amplifiers.

Mode	P-V (λ)	Strehl Ratio	Zernike 4 Astigmatism 45º	Zernike 5 Defocus	Zernike 6 Astigmatism 90º
OPCPA 9 sec Cycle	0.378	0.836	-1.29E-1	-6.87E-4	-5.86E-2
OPCPA 45B only	0.377	0.867	-7.37E-2	+3.39E-2	-8.24E-2
OPCPA 25B only	0.400	0.837	-1.30E-1	+9.00E-3	-2.67E-3
OPCPA 16B only	0.470	0.809	-7.21E-2	+2.0E-2	-6.39E-2
OPCPA 16C only	0.858	0.359	-2.26E-1	1.67E-1	-1.49E-1
OPCPA 9B only	0.819	0.429	-2.47E-1	6.62E-2	-3.06E-2

Figure 8. Comparison of aberration contributions from individual amplifiers.

It is worth noting that a significant defocus (Figure 9, over page) was observed from 16C and 9B rod amplifiers. It is significant that these two rod amplifiers contain silicate glass where all other rod amplifiers use phosphate glass. The conclusion reached at this stage was that a pump induced aberration from the thermal loading from the flash lamps in the silicate glass amplifiers was the probable cause of the defocus.

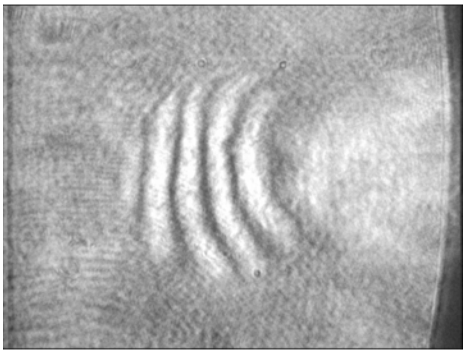
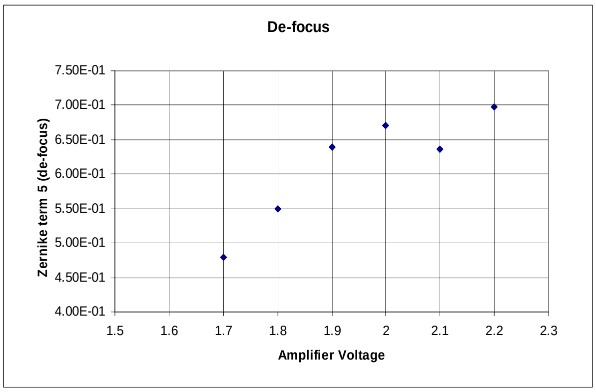


Figure 9. Interferograms from 16C (top) and 9B amplifiers.

An investigation to whether a reduction in the flash lamp voltage on the silicate amplifiers could reduce the pump induced aberration to a tolerable level. A reduction of the pump induced defocus was observed when the lamp voltage on the 16C silicate rod amplifier (see Figure 10) was reduced however this was not significant enough when offset against the reduction in the rod chain output energy caused as a result of the lower pump voltage.



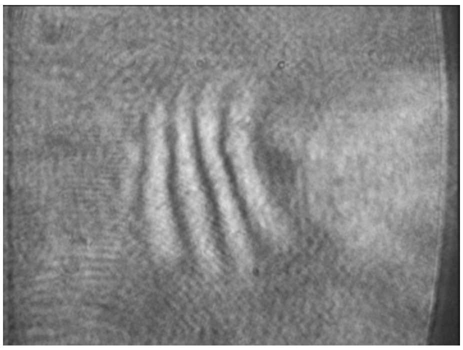


Figure 10. Reduction of Defocus against amplifier pump voltage.

Solution

The pump induced aberration was largely composed of a defocus which was reproducible on a shot to shot basis and the silicate glass amplifiers in Vulcan form a chain which is isolated from the phosphate rod chain. Because of these two facts it is possible to de-tune the spatial filter in the Silicate amplifier chain to compensate for the pump induced aberration. When running the adaptive optics to flatten the wavefront, the CW laser is propagated through the Phosphate chain, bypassing the detuned spatial filter. Thus when the shot is then directed through the mixed glass chain the compensating de-tuned spatial filter removes the pump induced de-focus from the silicate amplifiers, see Figure 11.

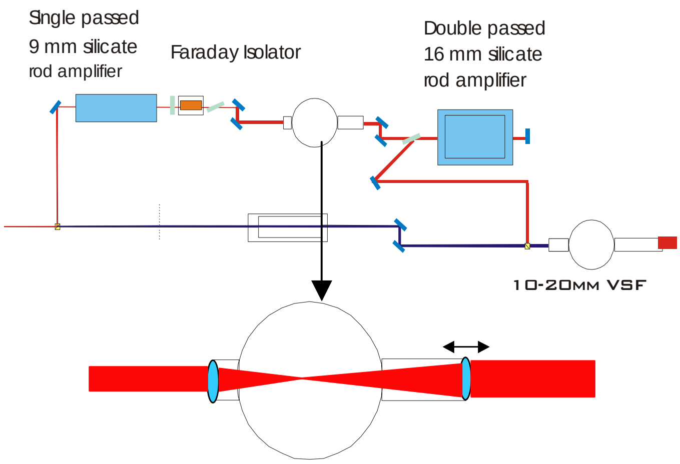


Figure 11. Compensation of pump induced defocus by de-tuning of spatial filter lens.

Result

A marked increase in the focal spot quality was observed when the silicate amplifier chain was de-tuned in compensation. Figure 12 shows a comparison of the spots along with the interferometric data. This improvement resulted in a factor of 9.3 decrease in spot area, likewise corresponding to close to an order of magnitude decrease in on target intensity.

Mode	P-V ([illegible])	Strehl Ratio (OFA)	Horizontal FWHM (pixels)	Vertical FWHM (pixels)	Area
Silicate 2 min shot AO run for silicate	1.35	0.164	66	72	14928
Silicate 2 min shot AO run for Phosphate	**0.453**	**0.775**	**196**	**226**	**139159**
					Factor of 9.3

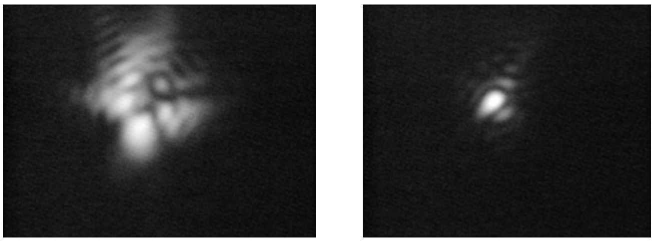


Figure 12. Focal spots for non compensated (left) and compensated states and interferometric data.

Conclusion

A pump induced defocus arising from the silicate glass rod amplifiers was identified as the cause of the drop in on target intensity on the Vulcan petawatt beam. A resulting de-tuning of the silicate rod chain spatial filter resulted in a significant improvement to the focal spot quality.

References

1. C Hernandez Gomez *et al.*,
A Radial shear interferometer, CLF Annual Report 1997/98

2. V.N Mahajan,
Zernike circle polynomials and optical aberrations of systems with circular pupils, Engineering and laboratory notes in optics and photonics news 5, December 1994