Implementation of a spectrally-resolved inverted-field autocorrelator for angular dispersion measurements in Gemini

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Introduction

Uncompensated angular dispersion of a laser beam, resulting for example from a misaligned compressor in a CPA system, degrades the quality of the laser pulses in a number of ways [1]. First, angular dispersion temporally chirps the beam, giving rise to group delay dispersion which lengthens the pulse and thus reduces the intensity, and third order dispersion that reduces the contrast of the laser. Second, dispersive elements result in an angle between the pulse-front and the phase-front of the propagating beam – a pulse-front tilt (PFT) [2]. This pulse front tilt also increases the duration of the pulse at the target position, and has an effect on important experimental outcomes such as electron-beam pointing. Finally, as each spectral component in an angularly dispersed beam propagates along a different axis, the resulting focal spot is elongated in the dispersion direction limiting the smallest spot size achievable, and therefore the on-target intensity.

For these reasons, it is critical that in addition to the pulse length (measured with a GRENOUILLE in the case of Gemini) the post-compressor angular dispersion is accurately measured and compensated for when optimizing the pulse compressors. At present this is done with a spatially-reversed Mach-Zehnder interferometer. This method has been successful in minimizing the observed angular dispersion in the target area, but has the disadvantage that several measurements are needed resulting in a data collection time of up to 30 minutes. These data are then analyzed offline, and so a regular measurement of the angular dispersion is not practical.

A new diagnostic is in the process of being implemented to resolve this problem. The system, which is described further in the next section, is similar to that currently in place but with the addition of a spectrometer to analyze the output of the interferometer [3]. Known as SRIFA (spectrally-resolved inverted-field autocorrelator), this will provide a real-time measurement of the angular dispersion of the Gemini beam, allowing in the first instance a daily measurement to be made, with the possibility of extending this to recording data on every shot.

SRIFA

For two waves travelling at a small angle θ to each other, for example at the output of an interferometer, the interference pattern across a plane observed along the x-axis is described by:

$$I \propto \cos\left[\frac{2\pi}{\lambda}\theta x + \Delta\phi\right],$$

where I, λ and $\Delta\phi$, are the intensity of the interference fringes, the wavelength, and the phase difference between the two beams respectively. The value of I is cyclic, and repeats for each integer value of $\theta x/\lambda$. The distance between two consecutive maxima, or the fringe separation Λ, is given by:

$$\Lambda = \lambda/\theta.$$

In the case of a standard interferometer, θ is generated by a slight tilt of a mirror in one of the interferometer arms, θ_{mirror}. In the case of a spatially reversed interferometer (see Figure 1), θ is a combination of θ_{mirror}, and twice the angle between the optical axis of the interferometer and the axis of propagation of the wave. For angularly dispersed beams this is a function of wavelength, $2 \times \theta(\lambda)$ and the fringe separation is then $\Lambda(\lambda)$.

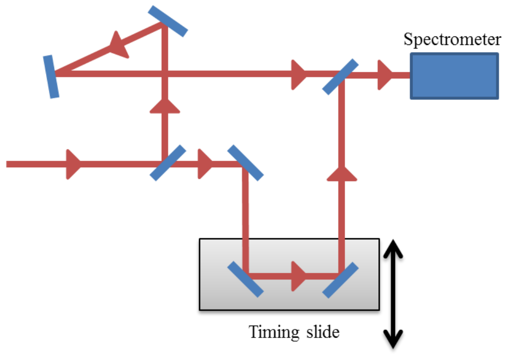

Figure 1. The setup of the SRIFA diagnostic, showing a spatially reversed Mach-Zehnder interferometer coupled to a spectrometer.

Analyzing the output of the interferometer with a spectrometer, and recording the data with a CCD camera, results in an interference pattern where $\boldsymbol{\Lambda(\lambda)}$ can be measured for each value of $\boldsymbol{\lambda}$ (see the next section for examples). Plotting $\boldsymbol{\lambda\backslash 2\Lambda}$ then gives a line whose gradient is the linear angular dispersion present in the beam. Higher order functions can be fitted to the data to extract higher orders of dispersion, but in the present case only linear dispersion is considered.

Analysis

Figure 2 shows simulated spectrally-resolved interferograms for two cases, one with no angular dispersion and one with an angular dispersion of -10 μrad nm^{-1}. In each case the CCD chip size was taken to be 5 mm x 5mm, the laser bandwidth was 750 – 850 nm, and a value of $\boldsymbol{\theta}_{\text{mirror}}$ = 1 mrad was used. Panels a) and b) show the non-dispersive and dispersive images respectively, with wavelength increasing from left to right. In Panel c) the measured value of $\boldsymbol{\lambda\backslash 2\Lambda}$ is plotted for each wavelength with hollow circles, and the solid line shows a linear least-squares fit to these data. With no dispersion the gradient of the line is zero, with an offset of 1 mrad corresponding to the tilt introduced from the mirror (which is constant for all wavelengths). With dispersion present the fringes in the interferogram are splayed, and the linear fit has a gradient of -10 μrad nm^{-1} as expected.

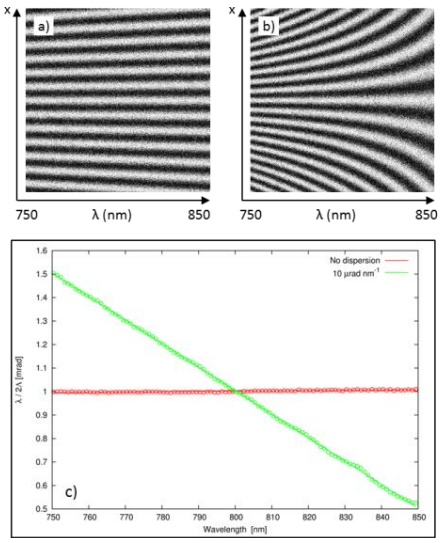

Figure 2. Simulated inteferograms with a) zero angular dispersion, and b) a dispersion of -10 μrads nm^{-1}. The points in Panel c) show the value of λ/2Λ vs. wavelength for every 5th column in the interferograms. The solid lines are the results of a linear fit to the extracted data points.

Implementation

The diagnostic has been built and installed in the Gemini laser area on the North beam. The leakage beam through the compressor is used for the measurements. An example of experimental data taken during the installation phase, along with a screenshot of the software interface, is shown in Figure 3. The next stage will be to validate the new diagnostic against the current method to ensure that the two are consistent. Once this has been done, then the SRIFA will be incorporated into the daily setup routine and the values of angular dispersion will be logged to eCat and displayed in Penguin [4].

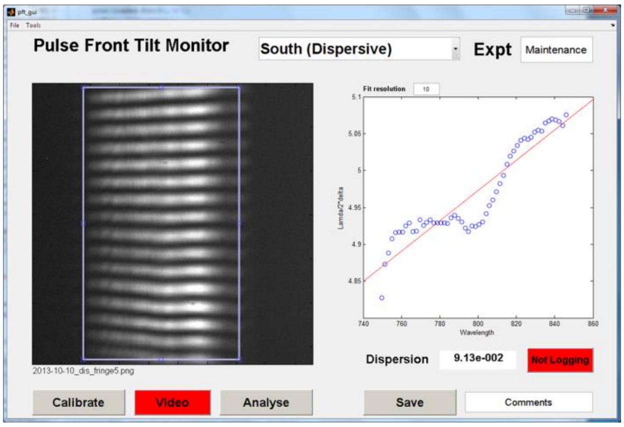

Figure 3. User interface for the new diagnostic, showing an example of raw data on the left, and the calculated dispersion on the right.

Acknowledgements

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