Gemini Timing Drift Stabilisation

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Abstract

A new method of analysis was implemented to improve timing drift stabilisation on Gemini, measuring delay on individual measurements of drift with an uncertainty of 9 fs. Code was written to move the split and delay stage in order to compensate for drift; in typical operating conditions delay due to drift was kept smaller than delay due to shot-to-shot jitter.

1 Introduction

Timing drift stabilisation is required on Gemini in order to keep a fixed time between the two beams, as many experiments require a consistent delay between them. The timing between the beams tends to drift over time, mainly due to differences in temperature across the laser area, so this needs to be corrected for. Located in the laser area LA3, the timing diagnostic consists of a spectral interferometer where the two beams of light interfere at an angle parallel to the slits in the grating [1]. The existing method of analysis of these images involved simply taking a Fourier transform along the horizontal and measuring the space between peaks, but this had a resolution limited by the range of frequencies of the beam, and could not measure delays below about 70 fs [2] due to the peaks being too close together.

A new method of analysis was implemented, which made use of the beams being incident on the diagnostic at an angle parallel to the grating. This reduced the uncertainty on individual measurements of delay and enabled the drift to be corrected for, so that changes in timing due to drift were less than those due to shot-to-shot jitter. It also meant that delays between the beams about 0 fs could be measured.

2 Method of analysis

The timing diagnostic produced an image of an interference pattern, where the horizontal axis represented frequency. First, to prepare the image for the fast Fourier transform, the image was linearly interpolated along the horizontal so that the distance between each consecutive pixel represented the same change in frequency. Unlike the existing method of analysis, a Fourier transform was first taken in the vertical of the interferogram. This resulted in an image containing two distinct bands - one of these was isolated by setting the value of all the pixels in the images except those near the band to zero. An inverse Fourier transform of this resulting image was taking in the vertical, back to the frequency domain. The imaginary part, the phases, were extracted from this. These phases were then 'unwrapped', meaning they were made continuous rather than mapping from pi to negative pi. As one band had been isolated, the change in phase ϕ with frequency f across the image was proportional to the delay τ between the two beams, according to the relationship

$$\tau = \frac{1}{2\pi}\frac{d\phi}{df}. \quad (1)$$

The image was cropped so that areas outside the interference pattern were ignored, and an average of the phases in the vertical were taken. The gradient of the average phase with respect to frequency was taken and this was divided by two pi to get the delay.

3 Implementation

The timing drift was managed by controlling the split and delay (SAD) stage, located in the laser area LA3. At set time intervals, typically 150 s, the delay of all the images in an extra autosave folder of the timing diagnostic were measured. The average delay was then taken and the stage was moved by the appropriate amount to counteract for the difference between the average measured delay and the intended delay. An interval of 150 s was used; as Gemini shoots at 0.05 Hz this meant that seven or eight images were averaged over. Once the images were measured, they were deleted from the folder so that they were not measured twice.

The amount to move was calculated from the delay using the equation:

$$d = 0.5\tau c, \quad (2)$$

where τ was the delay, d was the correction required and c was the speed of light. A factor of 0.5 was included as the light made a double pass along the stage. This correction was then communicated to the stage via Experimental Physics Industrial Control

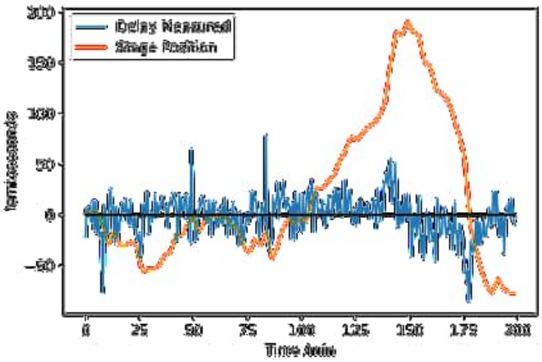

Figure 1: One of the test runs showing the measured delay and the position of the stage to correct for it (in time equivalent of the distance moved, relative to the stage's start position) against time. This run was taking one shot every 20 s, averaging over periods of 150 s. The A/C was turned on at 0 mins at 20°C and then set to 19°C at 40 mins. The heating was turned on to 23°C at 119 minutes, and then the A/C was set to 21°C at 163 mins.

System (EPICS). One process variable was written to, in order to control relative movements of the stage, and another representing the position of the stage was read so that the stage's position could be logged.

4 Results of tests

It was found that for individual measurements of delay, there was an uncertainty of 9 fs. The code was tested by running it to control the SAD stage in LA3, while changing the settings on the air-conditioning unit to induce drift, such as the test shown in figure 1. The code appeared to work well to correct for drift, keeping the RMS delay at 15 fs when temperature changes were similar to what could be expected during normal operation - this was the same RMS delay as when there was no significant drift (A RMS delay below this could not be achieved due to shot-to-shot jitter). RMS delay did increase where a large or sudden drift was induced, by creating a temperature difference between the north and south enclosures in LA3 of greater than 0.4°C or by changing this temperature difference suddenly, although this was a larger temperature variation than what was seen on a typical day.

Timing drift did not appear to be dependent on the temperature of the room itself, but instead appeared to be largely dependent on the difference in temperature between the two north and south enclosures, and the rate of change of this temperature difference with respect to time. The delays measured correlated fairly strongly with the difference in temperature between the

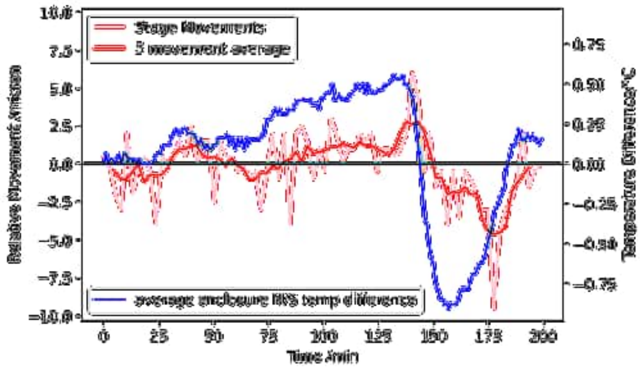

Figure 2: The amount the stage moved with each movement (blue line) and the average difference in temperature between the enclosures (red). The movements correlated moderately with temperature difference, except for the peaks at about 140 and 180 mins.

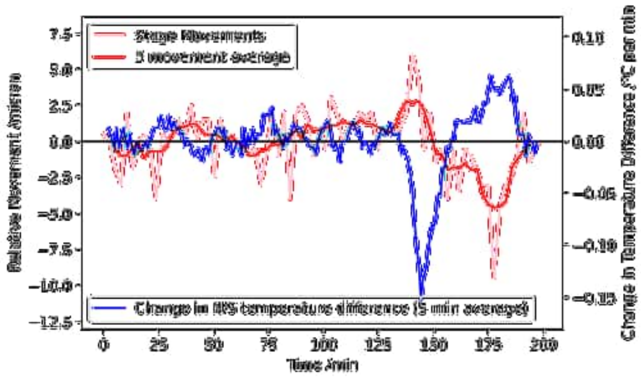

Figure 3: The amount the stage moved with each movement (blue line) and the average rate of change in difference in temperature between the enclosures with respect to time (red). Sudden stage movements (thus sudden drift) occurred when there where peaks in temperature difference.

enclosures (figure 2), except for sudden spikes in delay, which correlated instead with the large changes in the first time derivative of the temperature difference, as shown in figure 3.

Use in experiment

The code was successfully used in an experiment. Figure 4 shows the delay between the two beams over seven hours. Where the timing stabilisation is running and correcting to 2440 fs is shown in green, and where it has been stopped is in red. These shots were taken during the evening and night on a hot sunny day, so there was a large reduction in temperature as it cooled in the evening. This shows that the stabilisation code generally worked well, although it appears to take longer than

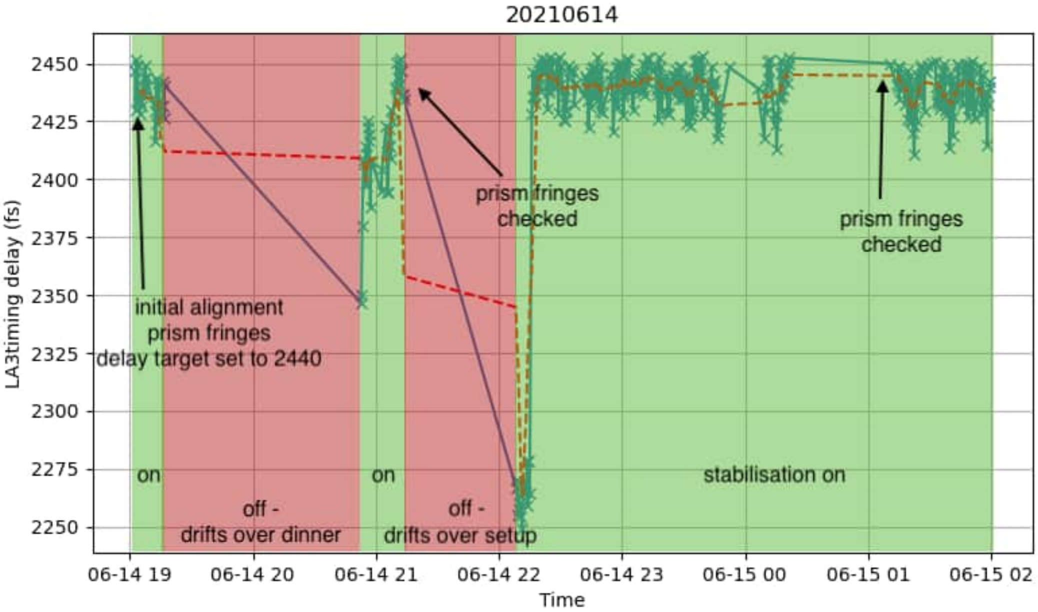

Figure 4: The delay between the two beams as measured in the laser area LA3, against time. The green crosses are full power shots and the red line is the 15 shot average. The timing stabilisation code was set to keep the drift at 2440 fs and was running except for the two red sections at about 7:15pm and 9:15pm. 'Prism fringes checked' refers to confirming the delay by measuring it in the target area with using a prism and spatial interference - these gave a similar values to the timing diagnostic in LA3. A few shots are excluded where there was issues with the pump laser energy, and a suitable spectrometer image could not be produced. [4]

what would be expected for the initial correction to correct towards 2440 fs.

5 Conclusions

The delay correction appeared to work well within typical temperature variations in LA3, assuming one shot was being taken every 20s. The code did require a run of shots where they were being taken every 20s for a while, and would have not worked so well when just a few shots were being taken at irregular intervals. The main limitations were in the averaging of shots and the effects of shot-to-shot jitter on measurements of drift. The effects of jitter on the measurements of drift could have been reduced by averaging over more shots, however this would have made the code respond slower to drift. Ideally, an optimum interval should be determined to find the best compromise between these. The stage itself was also a significant limitation of the drift correction - it had a precision of 1 micron, or 6 fs due to the double pass of light.

The measurements in delay were significantly more precise than the existing method for determining delay, as delays from individual images could be measured to almost an order of magnitude higher precision (9 fs as opposed to a fundamental limit of 37 fs [3]), and could still measure delays close to zero (instead of the existing method which could not measure delays below about 70 fs [2]). Temperature fluctuations between the enclosures typically does not exceed 0.3°C, which is within the range that the code corrects effectively for drift. However other causes of drift or larger temperature variations may limit the effectiveness of the drift correction.

The code also appeared to work well live during an experiment, although for an unknown reason it did seem to take more shots than expected before it corrected to the intended value of delay. This may have been due to how the users were running the program.

References

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[4] C. Colgan, 2021. Imperial College. Unpublished graph.