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Carrier-envelope Phase Drift Detection of Picosecond Pulses

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Abstract. A bandwidth-independent, linear and scalable method for carrier-envelope phase drift measurement demonstrated. Our experiments reveal that carrier-envelope phase drift of a picosecond pulse train can be directly obtained from the spectrally resolved interference pattern of a length-stabilized multiple-beam interferometer. The retrieved phase from the pattern correlates well with the strongly CEP-sensitive coupling signal between the frequency combs of the picosecond oscillator and an ultra-high finesse Fabry-Perot interferometer. Our results can lead to the generation of a robust CEP-stabilized seed pulse train for high resolution comb spectroscopy as well as to compact Compton X-ray and gamma-ray sources.

1 Introduction

The effects of the carrier-envelope phase (CEP) drift of mode-locked femtosecond oscillators have been extensively studied in the past ten years. Experiments in attosecond physics and ultraprecise frequency metrology [1] are critically relying on low-noise carrier-envelope phase (CEP) measurements of ultrashort pulses and subsequent low-jitter stabilization [2]. In picosecond regime, the number of optical cycles inside the envelope being two to three orders of magnitude higher, the CEP is not expected to yield noticeable effects in practical experiments. However, picosecond frequency combs produced by ultrahigh stability and high finesse Fabry-Perot (FP) resonators from ps pulses [3], are essential for compact Compton X-ray and γ-ray machines [4]. The power of the seed combs could be in theory drastically increased if their spectral stability is ensured in an alternative way to Fabry-Perot filtering. This alternative is provided by the unique relation between spectral position of the frequency comb, that is, the carrier envelope offset frequency and the carrier-envelope phase drift.

While recent methods for CEP drift measurement and stabilization have emerged into the single attosecond regime for Ti:sapphire lasers [5,6], this laser parameter is virtually inaccessible for a large class of lasers which either do not display sufficient, near octave-spanning spectral width or peak powers to satisfy the rather demanding constraints of f-to-$2f$ interferometry [7] and other related methods [8]. In response to this blind spot of laser characterization, we have recently proposed and demonstrated a linear method of CEP drift detection, based on a multiple-beam interferometer [9].
In this paper we demonstrate that the CEP drift of a picosecond pulse train can be measured to high accuracy and with a sufficient speed by a multiple beam interferometer (MBI). Based on that measurement, the CEP of the picosecond laser resonator could be stabilized for thermal fluctuations.

2 Experimental scheme

We used an all-linear optical method based on a multiple-beam interferometer for real-time measurement of CEP drift, since it does not have any bandwidth requirements. The path length of the MBI matched closely the repetition rate of oscillator and the output beam was directed into a high-resolution spectrograph. Since the delay between the subsequent pulses of the train is small, they interfere spectrally at the output of the MBI. With the use of a spectrograph, from the spectral position of these spectral interference fringes the CEP drift between the pulses [9] can be uniquelly deducted. Concerning the length of the interferometer, thermal drift and mechanical vibrations pose severe problems for our measurement application. For stabilization of the cavity length, a frequency stabilized He-Ne laser with sufficient coherence length was aligned collinearly with the ps pulse beam; and the signal of its interference pattern was feeded back to a piezo translator to control the length.

The 2 ps, transform limited pulses at 799 nm have been provided by a mode-locked Ti:sapphire oscillator at 76.4 MHz repetition rate (Coherent MIRA 900D). The pulses were directed into a vacuum confocal Fabry-Perot cavity (FPC) with a finesse of 30000 and a baselength of 2 m. (Fig. 1.) The laser oscillator was frequency locked to the FPC by a feedback system based on the Pound-Drever-Hall (PDH) method. The feedback was driven by the coupling signal from the beam reflected from FPC, which was produced by an electrooptic modulator (EOM) and measured by a photodiode (PDF). The feedback reacted on two actuators: a piezoelectric transducer (PZT) located inside the laser oscillator and an acoustooptic modulator (AOM) used as a frequency shifter in double-pass layout. These modulators were responsible for frequency stabilization in the ranges of 10 and 100 kHz of unity gain bandwidth, respectively. Using only one coupling signal (PDF) and PZT in the feedback loop, one essentially could lock f_{rep} to the FPC round trip with a relative precision $f_{rep}/(\nu F) \approx 10^{-12}$, whereas CEP was free running. The behavior of the laser/cavity coupling then provided a direct measurement of the CEP drift effects while the locking was still stabilized enough.

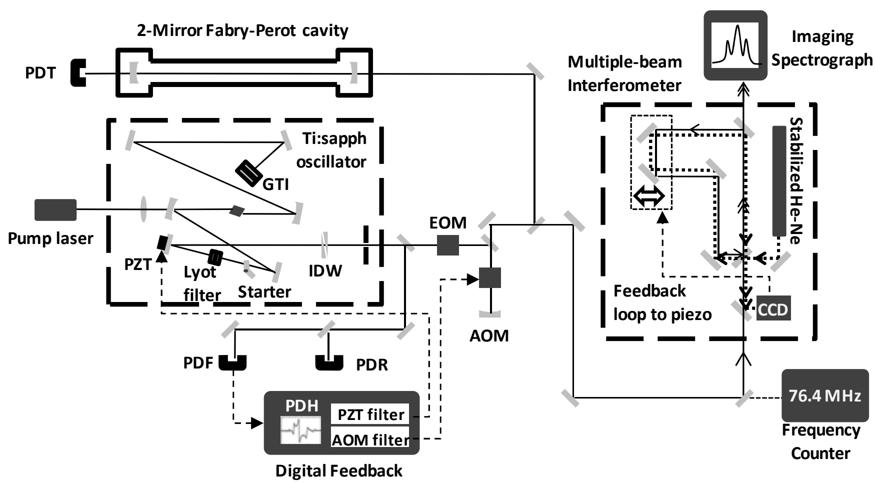

Fig. 1. Experimental setup consisting the ps oscillator with the Fabry-Perot cavity (top left) and the multiple-beam interferometer (right). The reflected beam from the Fabry-Perot cavity was used to drive the digital feedback of the oscillator and lock its frequency comb.

3 Experimental results of on-the-fly CEP drift variation

We used two independent methods to vary the CEP drift of the ps pulse train inside the oscillator. In the first experiment, we changed the pump power of the oscillator, while in the second one, the temperature of the Ti:sapphire crystal was varied. During the measurements, the coupling signal of the Fabry-Perot cavity and the interference pattern of the MBI were simultaneously recorded. According to the PDH method, the former is strongly related to the carrier envelope offset frequency. The CEP drift of the pulse train was obtained on-the-fly from the spectral interference pattern of the MBI.

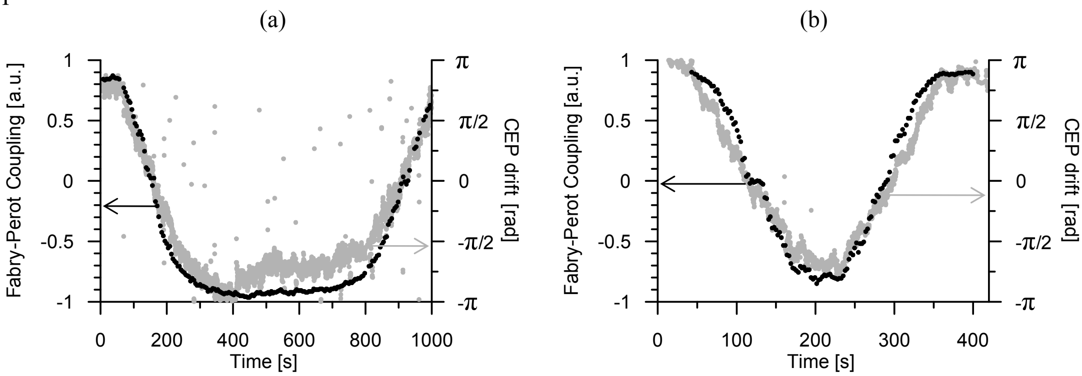

Fig. 2. Experimental results of controlling CEP drift manually by pump laser intensity (a) or the temperature of the Ti:sapphire crystal (b). Black data points represent the normalized and sign-corrected Fabry-Perot coupling signal, whilel the light grey plot is the CEP drift deducted from the MBI.

In both experiments (Fig.2.a and b), these quantities showed very clear correspondence with each other. To make a more direct comparison than just visual, we calculated also the expectable FPC coupling signal from the measured CEP drifts of the MBI, and compared to the recorded coupling signal. The correlation between the measured and estimated values was found to be better than 0.9.

4 Conclusion

We have measured, to our knowledge to the first time, the carrier envelope phase drift of picosecond laser pulses in two independent experiments with the use of multiple beam interferometry. This may open up the way of CEP stabilization of mode-locked picosecond lasers and hence ensure high resolution comb spectroscopy as well as seed pulses for Compton light sources.

References

1. T. Udem, R. Holzwarth, T. W. Hänsch, Nature **416**, 233 (2002)
2. L. Xu, C. Spielmann, A. Poppe, T. Brabec, F. Krausz, T. W. Hänsch, Opt. Lett. **21**, 2008 (1996)
3. V. Brisson, R.Cizeron, R.Chiche, E.Cormier, Y.Fedala, R.Flaminio, D.Jehanno, M.Lacroix, C. Michel, N.Pavloff, L.Pinard, V.Soskov, A.Variola, Y.Zaouter, F.Zomer, N. Inst. and Met. in Phy. Res. A **608** S75-S77 (2009)
4. A. Variola, J.P. Brasile, C.Bruni, R.Chehab, R.Chiche, R.Cizeron, F.Couchot, Y.Fedala, J. Haissinski, M.Jacquet, D.Jehanno, M.Lacroix, P.Lepercq, B.Mouton, R.Roux, V.Soskov, A.Vivoli, F.Zomer, N. Inst. and Met. in Phy. Res. A **608** S83-S86 (2009)
5. S. Koke, C. Grebing, H. Frei, A. Anderson, A. Assion, G. Steinmeyer, Nat. Photonics **4**, 462 (2010)
6. B. Borchers, S. Koke, A. Husakou, J. Herrmann, G. Steinmeyer, Opt. Lett. **36**, 4146 (2011)
7. H. R. Telle, G. Steinmeyer, A. E. Dunlop, J. Stenger, D. H. Sutter, U. Keller, Appl. Phys. B **69**, 327 (1999)
8. T. Fuji, A. Apolonski, F.Krausz, Opt. Lett. **29**, 632 (2004)
9. P. Jójárt, A. Börzsönyi, B. Borchers, G. Steinmeyer, K. Osvay, "*Agile linear interferometric method for carrier-envelope phase drift measurement,*" Opt.Lett. **37**, 836 (2012)