PROGRESS AND STATUS OF THE LASER-BASED SYNCHRONIZATION SYSTEM AT FLASH

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Abstract

The prototype laser-based synchronization femtosecond precision system installed at FLASH is continuously evolving and subject to improvements. In this paper, we give an overview of the present status, report on the latest developments and extensions, and discuss future challenges. Particularly the recent move to a new type of master laser oscillator led to an enhancement of the robustness and reliability. Consequently, research can focus upon the implementation of the electron bunch arrival time feedback, new technologies for timing distribution and the connection of external lasers to the optical synchronization system.

INTRODUCTION AND OVERVIEW

The free-electron lasers FLASH and the European XFEL demand a high timing accuracy between the electron bunches and external laser systems to fully exploit the short UV and X-ray pulses in time-resolved pump-probe experiments and for the seeded operation modes. The required precision can only be achieved with laser-based synchronization schemes. The scheme is based on the timing information delivered by a passively mode-locked master laser oscillator (MLO) as its repetition rate. This reference pulse train is distributed to the various locations at the accelerator with actively length-, i. e. transit time-stabilized fiber links, where it is used for diagnostics, the synchronization of external laser systems or, in the future, to connect the RF stations to the timing reference.

Presently, the system consists of four bunch arrival time monitors (BAMs, [1]), each of which is provided with the reference laser pulse via individual fiber links. The BAMs are located around the first bunch compressor, behind the second bunch compressor and at the end of the linac. This configuration allowed for a successful intra-train arrival time feedback operation [2, 3] for user experiments, and the permanent availability of arrival time data is highly appreciated by the FEL users at all.

Furthermore, three fiber links are installed to connect the laboratories of the pump-probe laser, the seed laser of the sFLASH experiment and of an electro-optic (EO) bunch diagnostics experiment. Those Ti:Sapphire oscillators can be synchronized to the optical pulse train with an extended RF-based scheme [4]. Additionally, a prototype optical cross-correlator for the EO experiment's laser had been build for an all-optical synchronization [5].

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TIMING REFERENCE

Master Laser Oscillator

In 2010, the previously used self-built erbium-doped fiber laser (EDFL) had been replaced by a commercial "Origami-15" SESAM-based laser system [6]. Since a stable and reliable timing reference is crucial for the synchronization system, special care had been taken in the characterization and the commissioning of the laser. Although the benefits of the commercial laser, such as maintenance-free operation and ultra-low timing jitter, overweigh, several problems and difficulties had been identified. As an example, we discuss the influence of the piezo actuator, which is required for the synchronization of the laser to the master RF oscillator of the accelerator, on the internal laser dynamics: It has been discovered that, besides the pulse duration, the center wavelength and the spectral width exhibit relative changes of 0.15% and 0.1%, respectively, over the complete range of the piezo voltage (red curves in Fig. 1). This has a negative impact on the fiber link stabilization scheme and the all-optical synchronization of external lasers, and required the setup of an active amplitude stabilization feedback acting on the pump power, resulting in a suppression of the effect in the order of a factor 20 (green curves). Recently, a second Origami laser was delivered, which will be installed for redundancy in case when the original laser fails. The influence of the piezo

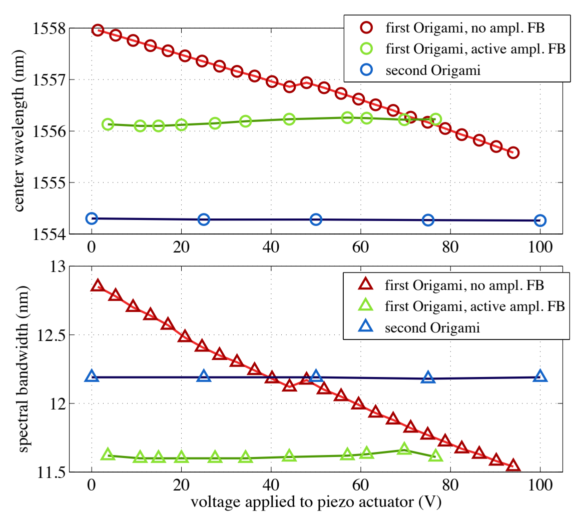

Figure 1: Comparison of the center wavelength (top) and the spectral bandwidth (bottom) of the two commercial laser systems as function of the voltage applied to the piezo actuator.

voltage on the center wavelength and the spectral width has been reduced to 2.6×10^{-5} and 8.2×10^{-4} (blue curves) without active amplitude stabilization, as the manufacturer (OneFive GmbH) developed a new internal setup after our investigations.

The center wavelength, as it can be seen in the upper plot in Fig. 1, had intentionally been chosen lower compared to the first laser, which will result in an improved dispersion compensation in the fiber links.

Local Distribution

Due to the large number of fiber links, the connection of the injector laser and for monitoring purposes, the reference laser pulse train from the MLO(s) is split and distributed to the devices in a free-space optical setup (named FSD) based on polarizing beam splitters and half-wave plates. The optical components are installed with custom-designed mounts and ultra-stable mirror mounts on an Invar base plate. Figure 2 (left plot) shows the optical power

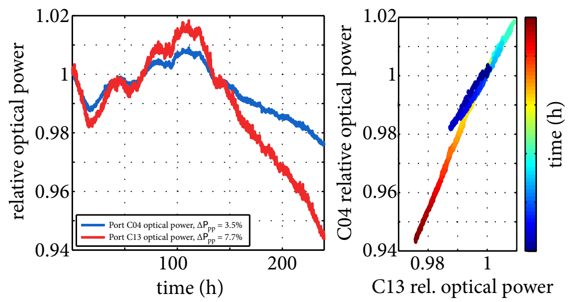

Figure 2: Drift of the optical power in the FSD over 10 days (left) and correlation of the two ports (right).

drift over 10 days measured with fiber-coupled amplitude monitors at two ports on opposite sides of the FSD. Although peak-to-peak changes of 3.5% and 7.7% are observed, these changes exhibit a strong correlation (right plot). Consequently, the FSD setup is internally fairly stable, but there seems to be a pointing instability between the laser and the FSD. This will be addressed soon, but it has to be decided whether an active beam position feedback based

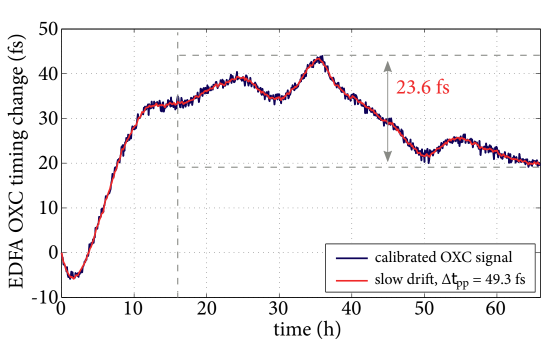

Figure 3: Timing drift of an EDFA connecting a fiber link unit to the free-space distribution unit.

on a quadrant detector and piezo-actuated mirror mounts will be used or a new Invar base plate will be designed, with the laser systems mounted on.

In order to fulfill the requirements on the optical power in the fiber link stabilization scheme, the units are connected to the FSD with an individual, dispersion compensated erbium-doped fiber amplifier (EDFA). The timing stability of such an EDFA, i. e. provided with light through the FSD, has been measured with respect to a reference pulse train directly from the MLO using a balanced optical cross-correlator (OXC). In Fig. 3 it can be seen, that the timing drifts by 50 fs over almost 3 days, which is related to temperature, and more importantly, humidity changes. Even after a period of 16 hours, when the system seems to have stabilized, a drift of 23.6 fs has been determined. Since this fiber section is not actively stabilized, those drifts are critical for the system, and further measurements will be carried out in the near future to determine to what extent this leads to a common-mode error. However, when the slow drift is removed from the data, the residual jitter amounts to $\approx$ 1 fs, which is well within the targeted jitter budget for the timing distribution.

FIBER LINK STABILIZATION

After the commissioning of the fiber link to the EO laboratory, strong amplitude noise was observed in the pulse train at the fiber link end. Particularly, the noise is largest when the link stabilization loop is closed. This required a workaround by locking an intermediate RF oscillator for the synchronization of Ti:Sapphire oscillators, adding complexity and cost [4] and preventing an all-optical synchronization scheme. Recently, the cause for the noise was found as interference of co-propagating pulse trains with the same polarization state in the polarizing beam splitter (PBC) of the fiber link unit. In an upgraded optical arrange-

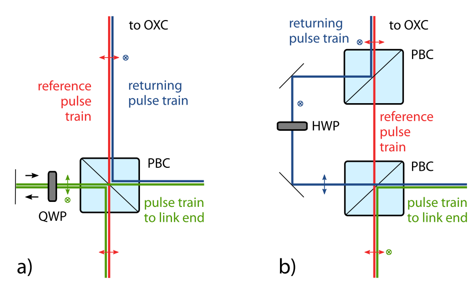

Figure 4: Optical path in the fiber link stabilization unit for splitting and recombining the pulse train into the reference and the one send to the link in a) the original and b) the upgraded units.

ment with a second PBC, this co-propagation is avoided by adding an extra delay to the pulse trains returning from the link end (see Fig. 4). This new configuration has been installed in one fiber link unit recently. Figure 5 (green curve) shows the measured amplitude noise for closed-loop operation. In comparison to the blue curve, where the extra delay is compensated for with the optical delay line in the link (resembling the original situation), the noise is strongly suppressed. Hence, the optical setup of all links installed in the future will use two PBCs, and the existing links will be replaced successively. It should be noted that also the fiber links to the bunch arrival time monitors exhibit this noise, since they have not been upgraded yet, but the employed detection scheme [7] in the BAMs acts as high-pass filter with a cut-off larger than ≈ 500 kHz. By this, the arrival time measurement is not, or only to some extent, affected by amplitude noise at lower frequencies.

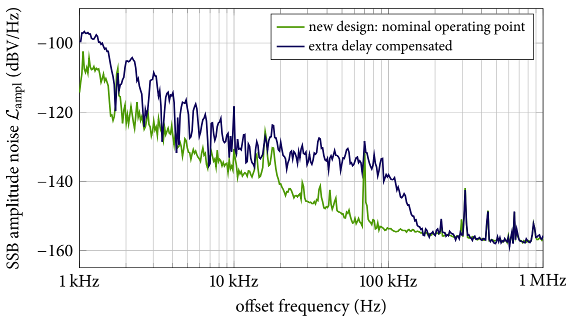

Figure 5: Single side-band amplitude noise measured at the "forward" optical power monitor in a link stabilization unit.

SYNCHRONIZATION OF THE PHOTO INJECTOR LASER

The photo injector drive laser oscillator (PTO) is connected to the optical synchronization system with a balanced optical cross-correlator, which enables the measurement of the PTO laser pulse arrival time with respect to the reference pulse train with sub-10 fs accuracy [8, 5]. The influence on the electron bunch arrival time can be studied using the BAM upstream of the first magnetic chicane, since there, the arrival time jitter is not yet compressed. Together with a special gun emission phase setpoint [9, 5], these two devices allowed for the investigation of a previously unknown effect in the BBO crystal, which is used for the generation of the UV pulses required by the photoemission process in the gun: The electron bunch arrival time across the macropulse changes by several picoseconds for different numbers of bunches in the train (see Fig. 6). The most likely reason for this is the pulse-induced heat load in the crystal. Moreover, the effect depends on the crystal tilt, and since the effect is similar for different bunch repetition rates, the time-scale is larger than 20 µs. Further investigations are currently ongoing, as this issue is critical for the long-pulse operation of FLASH.

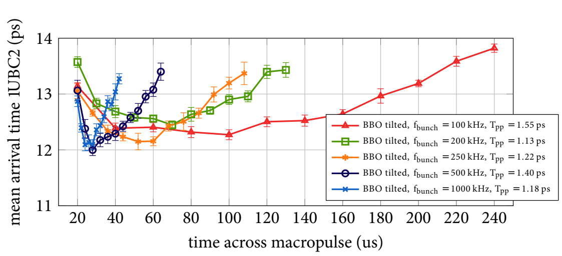

Figure 6: Bunch arrival time as function of the number of bunches in the macropulse at different repetition rates.

FUTURE PLANS AND CHALLENGES

The future extension of the accelerator (FLASH II) and the new operation modes will require the installation of up to 3 new BAMs with according fiber links, as well as the optical synchronization of the new seed- and pump-probe lasers. In 2011, the corresponding infrastructure installation will begin. More seizable goals are the installation of a fifth BAM with a new optical front-end upstream of the SASE undulators, the installation of an RF-based optical fiber link [10] in order to connect the RF stations of the accelerator, improvements on the humidity regulation in the synchronization hutch, the aforementioned upgrades to the FSD and the fiber links, as well as a more robust implementation of the optical cross-correlators for Ti:Sapphire lasers. Further studies on the arrival time will improve the longitudinal feedback, and an injector laser stabilization seems feasible with the upcoming fast uTCA electronics.

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