MEASUREMENT AND STABILIZATION OF THE BUNCH ARRIVAL TIME AT FLASH

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Abstract

To fully exploit the experimental opportunities offered by the $10-30\,\mathrm{fs}$ long light pulses from FLASH, e.g. in pump-probe experiments, precise measurements and control of the electron-bunch arrival-time on the $10\,\mathrm{fs}$ scale are needed. A bunch arrival time monitor which uses the optical synchronization system of FLASH as a reference has been developed for this purpose. The bunch-induced signal from a GHz-bandwidth beam pick-up is guided into an electro-optical modulator in which the periodic laser pulse train of the optical synchronization system experiences an amplitude modulation. Detection of this modulation allows to determine the bunch arrival time with a resolution of better than $10\,\mathrm{fs}$. The superconducting linac of FLASH generates trains of up to 800 bunches. The signals from the bunch arrival time monitor can be used for an intra-bunch train feedback stabilizing the arrival time to $40\,\mathrm{fs}$ (rms). The feedback is capable of generating well-defined arrival time patterns within a bunch train which are useful for overlap-scans in pump-probe experiments. First results from the feedback installed at FLASH will be presented.

INTRODUCTION

The FEL user facility FLASH generates light pulses in the wavelength range from $48\,\mathrm{nm}$ down to $6.5\,\mathrm{nm}$ with typical pulse durations of $10-30\,\mathrm{fs}$. Pump-probe experiments using these light pulses and an external laser require the precise knowledge and control of both, the pulses from the FEL, and those from the external laser.

For this purpose, an optical synchronization system is being developed at FLASH. The system is based on the distribution of ultra-short laser pulses within the facility using optical fibers. Such a system was first proposed at MIT in 2004 [1].

A mode-locked, erbium-doped fiber laser operating at a repetition rate of 216 MHz is used as a timing reference. The long-term stability of this master laser oscillator (MLO) is ensured by locking the repetition rate of the laser to a 1.3 GHz microwave oscillator. The approx. $100\,\mathrm{fs}$ long laser pulses are distributed within the facility using optical fibers which are actively length stabilized to better than $10\,\mathrm{fs}$ [2]. One of the most important applications for which the precise timing information is needed, is the synchronization of distributed lasers. Balanced cross-correlation will be used to ensure sub-10 fs timing stability between the external laser and the optical reference [3].

Even more challenging is the synchronization of the FEL light pulses. The difficulties here are the large length of the entire facility of about $300\,\mathrm{m}$ and the many sources contributing to an electron bunch arrival time jitter.

Figure 1 shows a schematic overview of the FLASH linac. In an RF gun the electron bunches are generated by photo emission. They are accelerated in superconducting cavities and longitudinally compressed in two bunch compressor chicanes. The most significant contributions to an electron bunch arrival time jitter are coming from the photo-cathode laser, the RF gun, and the first acceleration module. Due to the large R_{56} of the first magnetic chicane of $180\,\mathrm{mm}$, the latter one has the highest impact. An amplitude variation of $1\cdot10^{-4}$ in the first module corresponds to an electron bunch arrival time variation of $60\,\mathrm{fs}$. Due to the much smaller R_{56} of approx. $40\,\mathrm{mm}$ inside the second magnetic chicane, the influence of the second and third acceleration module on the bunch arrival time is much less.

MEASUREMENTS AND CONTROL OF THE BUNCH ARRIVAL TIME

In order to study and improve the timing stability of the electron bunches, a bunch arrival time monitor (BAM) has been developed, which uses laser pulses from the optical synchronization system to detect the zero-crossing of a transient signal generated by a beam pick-up with more than 10 GHz bandwidth [4, 5]. The performance of this scheme was studied by correlating the arrival times measured by two BAMs. The resolution of the BAM including the timing stability of the fiber link was found to be better than $6.7\,\mathrm{fs}$ (rms) [6].

Figure 2 shows the arrival time stability measured during a machine study period. The upper plot shows the arrival time of 400 bunch trains. The curves in red, green, and yellow show the arrival times for three consecutive bunch trains. As can be seen from these plots, not only the arrival time of the entire bunch train is changing but also the arrival time distribution along the bunch train. This makes it impossible to flatten the arrival time distribution using a feed-forward control. The bottom plot shows the rms ar-

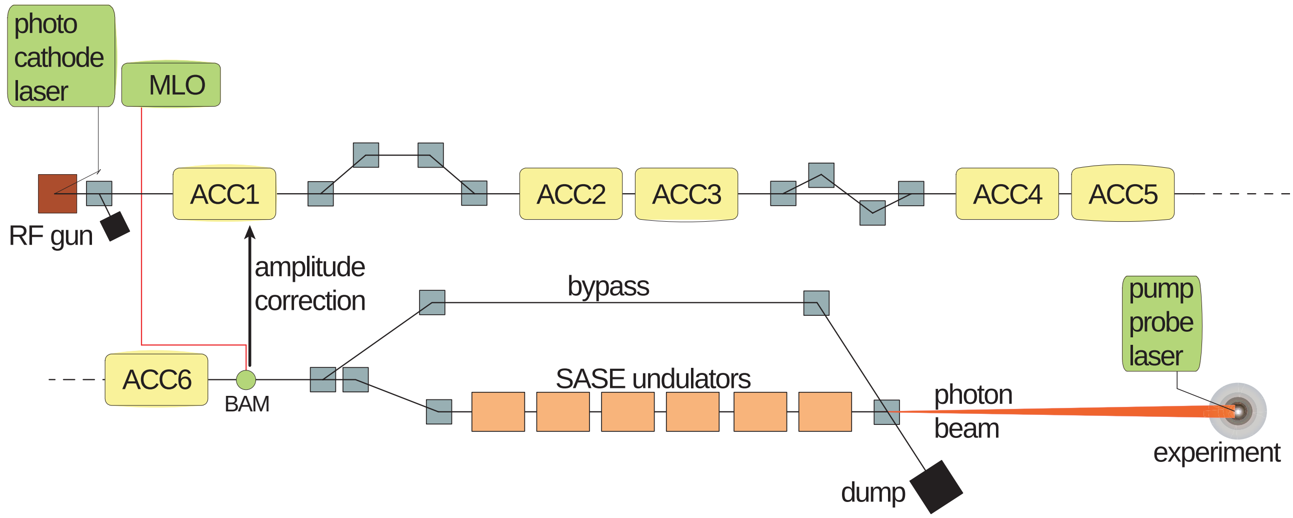

Figure 1: Schematic layout of the FLASH linac. In the arrival time feedback, the measurement of the BAM is used to correct the accelerating field in the first acceleration module.

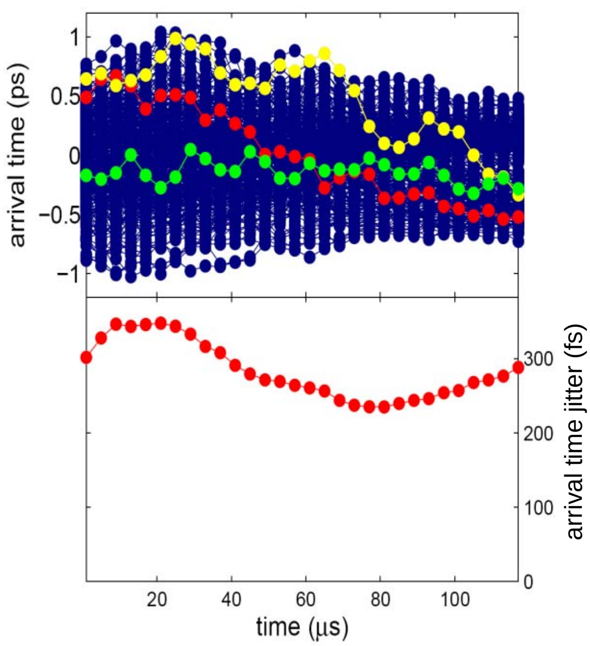

Figure 2: Arrival time stability without the arrival time feedback active. Top: arrival times of 400 bunch trains (blue). The curves in red, green, and yellow show the bunch arrival time of three consecutive bunch trains. Bottom: arrival time jitter over 400 bunch trains.

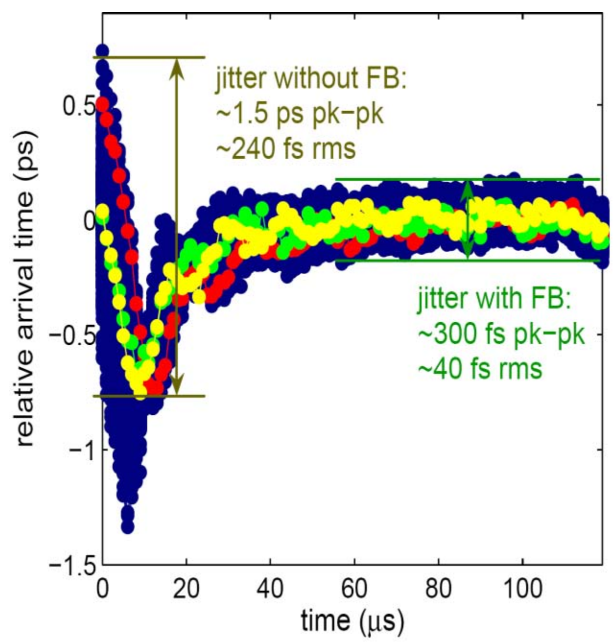

Figure 3: Arrival times of 400 bunch trains with the arrival time feedback active (blue). The curves in red, green, and yellow show the bunch arrival time of the consecutive bunch trains.

rival time stability which is on the order of $300\,\mathrm{fs}$. During these measurements, the bunches were not compressed inside the magnetic chicanes. In a typical FEL operation, the arrival time stability is on the order of $150 - 250\,\mathrm{fs}$. This smaller arrival time jitter is achieved by further optimized RF settings and due to the fact, that incoming arrival time jitter from the photo cathode laser and the RF gun is compressed inside the magnetic chicanes.

In order to improve the arrival time stability, an intra-bunch train feedback was implemented. The arrival time measured by the BAM is processed in an FPGA based controller board and a PID controller is used to calculate an amplitude correction for the first acceleration module. Figure 3 shows the arrival time stability along the bunch trains with the feedback active. Since there is no correction signal available for the first bunch of the bunch train, this bunch is not stabilized by the feedback. The large arrival time change of the first few bunches is due to beam loading inside the acceleration modules. After a latency of several microseconds, the feedback is compensating for this and after about $30 - 40\,\mu s$, the arrival time is stabilized. The long time needed to stabilize the pulse train is due to

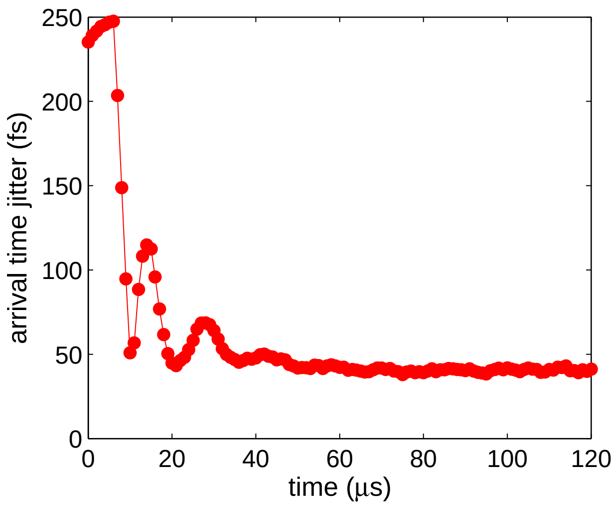

Figure 4: Arrival time jitter over 1200 bunch trains with the arrival time feedback active.

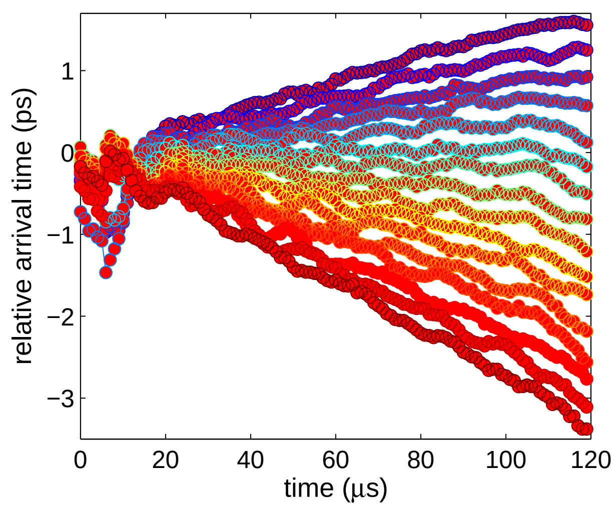

Figure 5: Generation of well defined arrival time slopes along the bunch train. The different colors correspond to different settings of the arrival time set-point.

the low bandwidth of the superconducting cavities and the large amount of RF power needed for fast amplitude corrections. The measurements with the stabilization active were done with slightly compressed electron bunches.

The arrival time jitter along the bunch train is depicted in Fig. 4. A reduction of the rms arrival time jitter from 250 fs without the feedback to 40 fs for the stabilized case could be observed.

An interesting feature of the feedback is the possibility to generate well defined arrival time patterns along the bunch train. Figure 5 shows the arrival time along the bunch train for different settings of the arrival time set-point. As one can see, clean arrival time slopes can be generated, which might be useful in pump-probe experiments to perform complete delay scans within a single bunch train.

With the current configuration, the first bunches inside the bunch train cannot be stabilized. For experiments which need stable bunch arrival times also for the first bunches, a fast kicker magnet could be used to perturb the first bunches of the bunch train before they produce FEL radiation. In order to increase the regulation bandwidth, it would be helpful not to use the superconducting cavities for the amplitude control but a separate, normal-conducting cavity.

SUMMARY AND OUTLOOK

We demonstrated a bunch arrival time feedback with which we could reduce the bunch arrival time jitter from 240 fs (rms) for the unstabilized case to 40 fs (rms) with the feedback active. The feedback is using the arrival time information measured by a BAM to act on the amplitude of a superconducting acceleration module upstream a magnetic chicane. With the demonstrated feedback, all sources of arrival time jitter are compensated by a single actuator. For an optimized overall performance, the different jitter sources in the machine have to be measured and controlled separately which requires additional timing monitors, as well for the photo cathode laser pulses, as for the electron beam.

Despite the bunch timing, another important parameter is the bunch compression process. The next step to further extend the longitudinal feedback system, will be to control in addition to the amplitude also the phase of the first acceleration module on the basis of beam based measurements using a bunch compression monitor.

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