RECENT UPGRADES OF THE BUNCH ARRIVAL TIME MONITORS AT FLASH AND EUROPEAN XFEL

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Abstract

In modern free electron laser facilities like FLASH and European XFEL a high resolution intra train bunch arrival time measurement is mandatory, providing a crucial information for the beam based feedback system. At FLASH and European XFEL a reliable arrival time detection with a resolution better than 0.1‰ is required for a broad range of bunch charges, from 1 nC down to 20 pC. The system developed is based on cross-correlation of ultra-short laser pulses and RF signals (in an electro-optical modulator). Several bunch arrival time monitors (BAM) were developed and are in operation at FLASH for nearly ten years. A major upgrade involved the development of new hardware and software based on the MTCA standard. Special operation mode at both facilities includes the possibility to subdivide the bunch train in up to three segments, each with different bunch energy and charge, causing variation of the time jitter within the bunch train itself. A further upgrade includes the measurement of the arrival time and application of delay correction for each of the three segments. In this paper, we describe the development, installation and commissioning of the hardware, firmware and software of the new system.

INTRODUCTION

At the FLASH and European XFEL a beam based feedback for the electron bunch is mandatory to ensure the expected photon beam quality delivered at the experimental stations. Crucial information for the feedback system is provided by the Bunch Arrival Time Monitors (BAMs) which measure along the acceleration section of the machine, the timing of the electron bunch with respect to a pulsed laser provided by a central Master Laser Oscillator (MLO), which is synchronized with the RF signal [1].

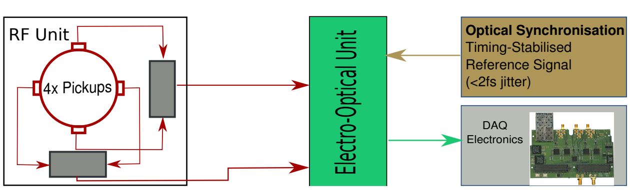

Figure 1: Basic Layout of the three BAM main components. The reference signal is provided by an external source, the laser-based synchronization system.

BASIC LAYOUT OF THE BAM

In this section we describe shortly the main components of the BAM system and their working principles. As Fig. 1 shows, the BAM system is composed of three parts, the RF unit, the electro-optical unit and the data acquisition system. The electro-optical unit is the core of the system. It combines the signals from the RF unit and a reference signal provided by an external source to perform the time arrival measurement. The result of this combination is then sent to the Data Acquisition System (DAQ).

- **The RF Unit**. The electromagnetic field induced by the electron bunch is captured by four broadband pickups. Two opposite pickups are combined to reduce the dependence of the signal on the bunch transverse position [2].
- **The Electro-Optical Unit**. Timing-stabilized laser pulses are provided as a reference signal to this unit. This signal serves also as clock for the DAQ electronics. The peak height of the pulses is modulated upon cross-correlation with an RF-signal, thus providing a temporal response from which the arrival time can be detected [3].
- **DAQ and Control** Dedicated electronics, firmware and software were developed to configure and control the single subsystem and for data acquisition [4]. Part of the electronics was developed using Micro Telecommunications Computing Architecture (MTCA) standard [5].

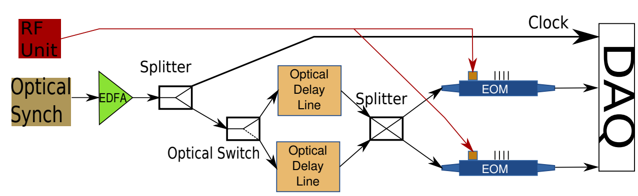

Figure 2: Basic Layout of the Electro-Optical Unit.

THE ELECTRO-OPTICAL UNIT

Figure 2 shows a schematic of the electro-optical unit and its parts. Each laser pulse provided by the MLO is split after being amplified and part of it (10%) sent to DAQ as clock signal. An optical switch sends the other part to an optical delay stage and after being split again, the laser pulses are combined in the electro-optical modulator with two RF signals coming from the pickups. There are two optical delay stages (planned to become three in the future), one for each sub-macropulse (related to different SASE beamlines), in order to be able to set different delays to each of them. After the laser pulses being modulated, these are sent to the DAQ electronics.

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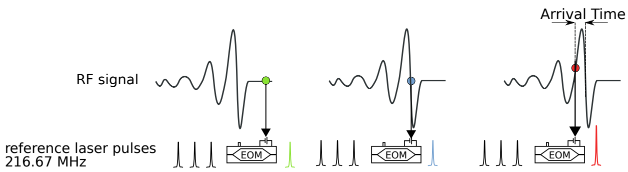

Figure 3: Working principle of the EOM. If no RF signal is encountered by the laser pulse or the laser pulse is perfectly synchronized with it, no change in the laser pulse height is observed (left and middle figure). if the two signal are not synchronized the pulse height is modulated (right figure).

Electro-Optical Modulator

The distance between 2 peaks of a RF signal is in the order of 10 ps while the ringing can take up to several 10 nanoseconds. The laser pulses have a FWHM of ~ 1 ps and a period of 4.6 ns. As already mentioned both signals are fed to an Electro-Optical Modulator (EOM). If a laser pulse encounters no RF signal, it experiences no modulation so its pulse height remains unaltered. If a RF signal is encountered, but laser pulse and RF signal are synchronized, still no modulation is observed. On the other hand if a RF signal is encountered but the two signals are not synchronized in time the pulse height is altered, i.e. modulated. This modulation is related through a non monotonic function to the arrival time, i.e. the distance in time to the position with both signals synchronized. (Fig. 3) [6]. The electro-optical unit is equipped with two EOMs, each with different settings, providing two different sensitivities to bunch charge.

Optical Delay Line

Ideally the working point of the BAM is where the laser pulses remain unmodulated, i.e. perfectly synchronized with the electron bunches. In order to calculate the arrival time properly and with high resolution, any deviation from the ideal working point has to stay in the region where the relation modulation - arrival time is monotone. Slow drift in the accelerator machine can move the working point outside the dynamic range for which the measurement gives meaningful results. For this reason a proper delay (negative or positive) must be applied in order to keep the working point in this region. Fig. 4 shows an optical delay stage developed for this purpose. The timing is adjusted by a retro-reflector mounted on the a commercially available stepper motor. The laser pulse entering the stage in the bottom right side, is coupled out from the fiber through a collimator and by means of two mirrors sent to the reflector, then being sent back to a second collimator which couples the laser pulse in the output fiber. Present setup allows to apply a maximum delay of ±130 ps, where the size of the monotone region is around 7 ps. Two RF signals are provided and the Electro-Optical Unit is equipped with two EOMs. Each EOM is configured to operate in a different range of bunch charge.

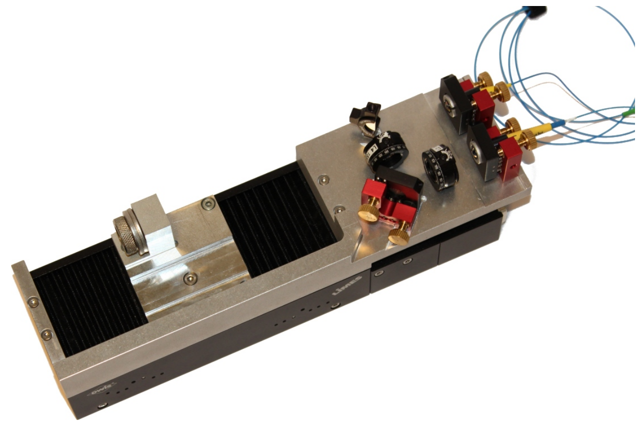

Figure 4: The delay stage is mounted on the linear stepper motor. For calibration purpose an encoder can be attached to the stepper motor as well (not shown in the photo).

Optical Switch

Modern X-Ray sources such as FLASH and European XFEL have the capability to drive multiple SASE beam lines, providing individually to the end user photon beams with different properties like wavelength, pulse length and intensity [7]. This involves to have bunches with different energies and charge inside the same bunch train. The bunch train for both facilities is divided in two parts which can have different properties (see Fig.5). Since different energies and different charges imply different jitter and arrival time, we must have the possibility to set different delays, so multiple ODLs have to be employed. In order to select the proper ODL an optical switch is used. The shape of the laser pulses are preserved and a maximum amplitude loss of ≈ 15% was measured. Moreover, the switching time was estimated to be in order of ≈ 100 ns, much smaller than 50 μs, i.e. the distances between the two bunch groups in a bunch train.

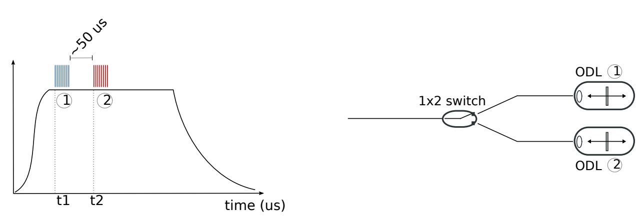

Figure 5: The bunch train at FLASH and European XFEL can be divided in two or more groups of bunches, each with different characteristics. This implies the necessity to set the delay time individually for each group of bunches and thus to have two or more ODLs.

Electronics

In this section we describe the main electronic boards used to control and monitor all the subsystems in the electro-optical unit. The dedicated electronics for the DAQ will be described in a separated section. All boards described in this and next section were developed in DESY [5].

Temperature Monitoring and Control Board (TMCB) This board provides 14 ADC, 10 DAC channels and 20 configurable General Purpose Inputs and Outputs (GPIOs). The board provides thus the possibility to set the proper voltage for the EOMs, to read several temperature and humidity sensors as well as the interface to 2 temperature controllers. The Board is stand alone and communication occurs via Ethernet or optical fiber.

Laser Diode Driver (LDD) This board is composed of a carrier and up to 8 mezzanines (only one in case of BAM), each providing a current source for a laser diode used for laser pulse amplification. Each mezzanine provides an Ethernet and a CAN bus interface and it can operate stand-alone.

Fuse Relay Board (FRED) The board allows control and monitor of up to 8 DC voltage channels, with individual fuses and current limitations for each channel. It has an Ethernet interface and it is suitable for stand-alone operation.

FMC20 with DFMC-MD22 The FMC20 carrier board can be equipped with two MD22 mezzanine boards. Each mezzanine can control up to 2-phase bipolar stepper motors, operating in a MTCA crate. The board has a PCIe connection to allow high level software to access the firmware registers.

DAQ AND CONTROL

The DAQ receives clock and modulated laser pulses through three photo-diodes. Onboard attenuator for the laser pulses are available which can be set via FPGA registers. After sampling the two signals with 16 bit ADCs, the data are filtered in order to acquire only the modulated laser pulse and specific unmodulated ones, used later for normalization. The firmware in FPGA performs some mathematical operations on the data, among them a division. The data are stored in internal RAM and then transferred through DMA to the DAQ Computer. Mathematical operations are necessary because a raw (non calibrated) value of the arrival time must be calculated and sent via optical link to the Low Level RF System for the fast beam based feedback. This operation is time critical and thus it must be performed at the firmware level. A clock distribution chip performs clock synchronization as well as application of a delay to the clock to allow the ADCs to sample any desired point along the laser pulse.

Electronics

The DAMC-FMC25 carrier board provides the FPGA for basic data processing, a second FPGA for board management as well as some additional diagnostics. The dual mezzanine DFMC-DSBAM contains three photo diodes to couple the electronics with the laser pulses, the clock distribution chip and four 16 bit ADCs [5].

SOFTWARE

The high level software for control and data acquisition is written using C++ language and the DOOCS framework [8]. The Framework ChimeraTK [9] was employed to access the register of the MTCA and TMCB boards. For the LDD and FRED boards dedicated libraries were developed. The main tasks of the high level software are the following

- Setting the various parameters for the firmware, e.g. data filter or ADC clock delays.
- Download and save in a persistent way the data.
- Perform the calibration to transform modulation in time.
- Perform slow feedback in order to keep the working point in the monotone region of the modulation - arrival time relation.

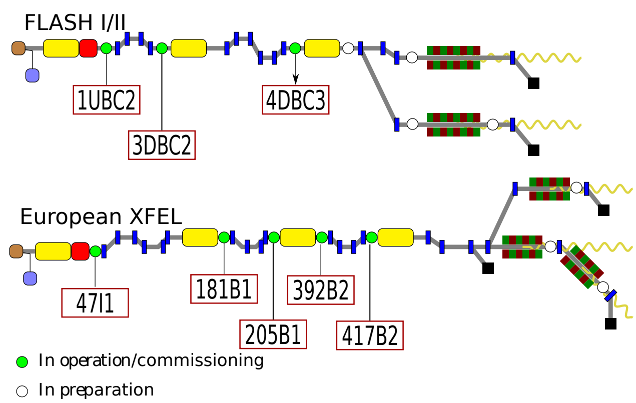

Figure 6: Positions and labels of the installed BAM systems along the beamline by FLASH and European XFEL.

INSTALLATION AND COMMISSIONING

At the moment three BAM systems are fully employed at FLASH and five are in commissioning at XFEL. The systems at FLASH and XFEL share the same DAQ system, including firmware and high level software for readout, while the XFEL has the newest generation of the RF and Electro-Optical Unit. An upgrade at FLASH is foreseen by the end of 2017 as well as the installation of new systems in both machines (Fig. 6) [10]. Table 1 shows the relative resolution measured for the FLASH BAM systems.

Table 1: Measured Resolutions for the Bunch Arrival Time Monitors at FLASH

BAM	Resolution in %
1UBC2	0.2
3DBC2	0.16
4DBC3	0.14

REFERENCES

[1] H. Dinter *et al.*, in *Proc. FEL'15*, pp. 478–482.

[2] A. Angelovski *et al.*, "Evaluation of the cone-shaped pickup performance for low charge sub-10 fs arrival-time measurements at free electron laser facilities", Phys. Rev. ST Accel. Beams 18, 012801 (2015).

[3] S. Schulz et al., "Femtosecond all-optical synchronization of an X-ray free-electron laser", Nature Communications 6, 5938 (2014).

[4] M.K. Czwalinna *et al.*, in *Proc. IBIC'13*, pp. 749–752.

[5] MicroTCA, `http://mtca.desy.de`

[6] A. Kuhl *et al.*, in *Proc. IBIC'13*, pp. 782–785.

[7] K. Honkavaara et al. in *Proc. FEL'14*, pp. 635–639.

[8] DOOCS, `http://tesla.desy.de/doocs/index.html`

[9] G. Varghese *et al.*, "ChimeraTK - A Software Tool Kit for Control Applications", presented at IPAC17, Copenhagen, Denmark, May 2017, paper TUPIK049, this conference.

[10] H. Dinter, "Longitudinal Diagnostics for Beam-Based Intra Bunch-Train Feedback", Ph.D. thesis, Hamburg, Germany, in preparation.