

UPDATE OF THE BUNCH ARRIVAL TIME MONITOR AT ELBE

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Abstract

The bunch arrival time monitor (BAM) at the radiation source ELBE has been upgraded twofold. In order to achieve a higher precision a new frontend has been designed, based on a development by DESY, that uses state of the art 50 GHz electro-optical modulators (EOMs). The frontend allows for thermal control of critical components and monitoring of system parameters. The modulated EOM signals and monitoring data are distributed to a new readout electronic. The new MicroTCA-based receiver is based on a dedicated FMC card developed at DESY that is installed on an FMC25 carrier board. The arrival time is calculated on a FPGA with low latency and can be used for machine diagnostic. The code has been adapted to enable the processing of a data stream of the continuous train of electron bunches, allowing for the implementation of a cw beam based feedback in a later step.

INTRODUCTION

ELBE Accelerator

ELBE is a superconducting linear accelerator in user operation since 2002. It generates electron bunches with an energy up to 40 MeV in continuous wave mode (cw) up to a repetition rate of 26 MHz. A thermionic DC gun can inject up to 100 pC bunches, while a superconducting RF gun (SRF Gun) is used for high charge mode up to 300 pC. The main accelerator consists of two superconducting modules, housing two TESLA-type cavities each.

ELBE can drive various secondary sources, like a neutron source, a positron source, a bremsstrahlung setup, two infrared free electron lasers and a THz facility.

BAM Principle

The described bunch arrival time monitor is using an actively stabilized reference signal, provided by a laser-based synchronization system and distributed over polarization maintaining optical fibers. The laser pulse signal is fed into an electro optical modulator (EOM). The RF input of the EOM is connected to a broadband beamline pickup, which takes a probe of the electric field of the electron bunches passing by. The two signals are aligned in time such, that the most pronounced slope of the pickup signal coincide with one of the pulses in the laser pulse train. This leads to a strong amplitude modulation change of a single laser pulse when the timing between laser reference signal and pickup signal is changed. By using this scheme, the arrival time information is mapped into an amplitude modulation of all laser pulses that coincide with the pickup signal in the EOM [1].

BAM Upgrade Motivation

The old BAM setup was using custom hardware for the signal conditioning and National Instruments PXI hardware for the digital data processing [2]. This configuration allowed no fast data transfer to the digital low level radio frequency (LLRF) controller, which is needed to apply a feedback controller to stabilize the arrival time actively.

For the EuropeanXFEL a BAM frontend and readout electronics has been developed which enables arrival time measurements with high accuracy [3] and fast data transfer to connected clients. This system has been adapted for the use at ELBE. The firmware was modified to enable the processing of continuous wave data.

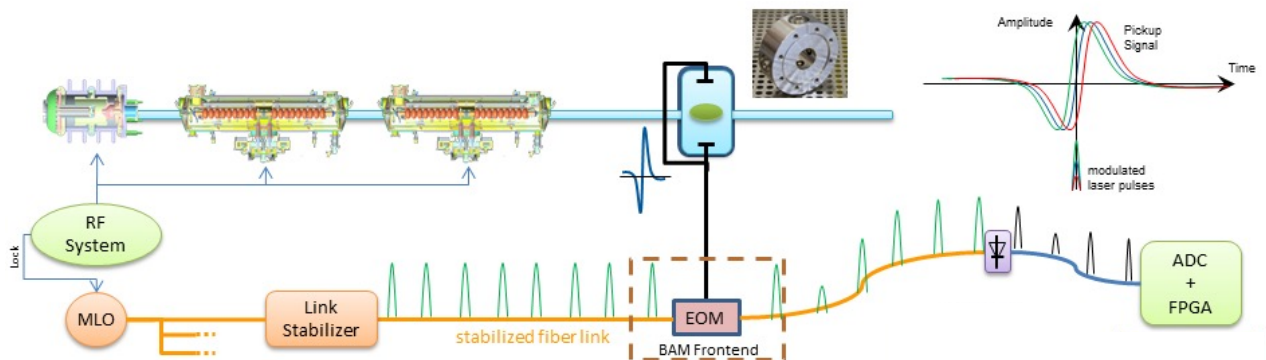


Figure 1: Bunch Arrival Time measurement scheme

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BAM UPGRADE

This section describes the new frontend and backend of the bunch arrival time monitors at ELBE.

Frontend

The electrical field probe signal is provided by a 40 GHz beamline pickup [4]. The signal is transmitted to the frontend electronics using 1.8 meters of low phase drift cables.

The frontend electronic is a four height unit 19 inch module. Figure 2 shows a block diagram of the device. It houses the power supplies, the electro-optical devices and a Temperature and Monitoring Controls Board (TMCB) for the bias voltage control of the EOMs and temperature monitoring. The data communication to the backend is done an optical fiber link (SFP+).

The original design was housing several delay stages to adjust the temporal overlap between laser signal and beam pickup signal. The main delay stage has been removed from the frontend and placed right before the link stabilizer in the temperature controlled synchronization laboratory. The position of this stage is read back with an calibrated encoder and used as a reference for relative timing shifts and calibration. This simplifies the BAM frontend and makes the delay stage easier to access and less prone to environmental changes. The gained space was used to integrate the power supply which used to be an additional module.

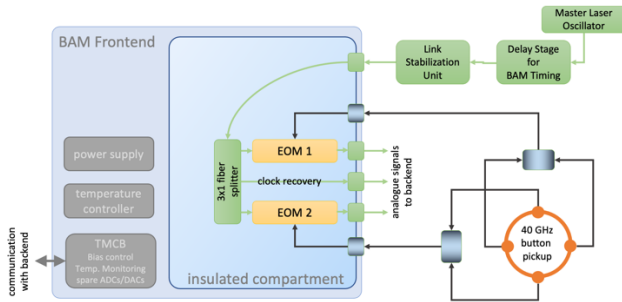


Figure 2: BAM Frontend Block Diagram

The components after the end mirror of the fiber link are outside the actively stabilized loop and need therefore special treatment. These components are assembled in a dedicated temperature stabilized compartment with a few Milikelvin temperature drift. A fiber splitter divides the reference signal in three paths. While one is left unmodulated to regain the laser clock phase in the backend, the two other paths are fed into two electro optical modulators. One is used for coarse measurements and therefor equipped with a 20 GHz EOM, the other is optimized for high accuracy measurements by applying a 50 GHz EOM (Optilab IML-1550-50-PM) at low modulation voltage of 3 V. Usually the high accuracy path is used for machine studies and test of beam based feedback schemes. Figure 3 shows a photograph of the BAM frontend with power supply and open temperature stabilized compartment.

The Frontend sends the modulated laser signals and the clock signal through non-stabilized singlemode fibers to the backend where the signals are processed.

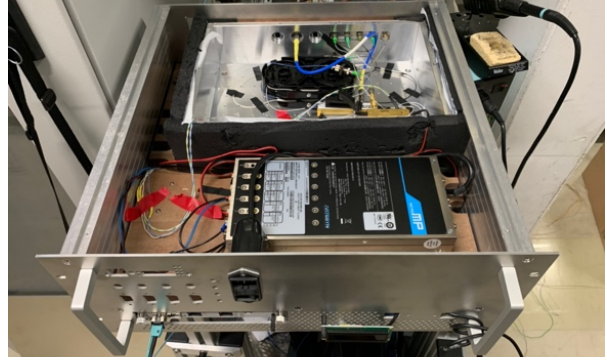


Figure 3: BAM Frontend Photograph

Backend

The backend is a standard MicroTCA.4 crate, equipped with Power Module, MCH, CPU, Timing Receiver and FPGA carrier boards. The timing card receives the accelerator triggers and sends it through the backplane to the DAMC-FMC25. This carrier board holds the FMC-DSBAM, which is the central part of the backend. It recovers the laser clock at 78 MHz and aligns its internal ADCs accordingly. One ADC per EOM is dedicated to the baseline, while another one is sampling only the peaks. In firmware the ratio between modulated sample and adjacent unmodulated samples is calculated and send to the server application and through a dedicated SFP+ link to the beam based feedback controller.

The original firmware was tailored to macro pulsed beam operation in different configuration. The firmware has been adapted to be able to process continuous wave operation data and to transmit it to the beam based feedback controller through an optical link (SFP+).

A second carrier board (DAMC-FMC20) carries a quad SFP+ module which is used to communicate with the TMCB, installed in the BAM frontend.

The server application has been developed in the ChimeraTK framework [5].

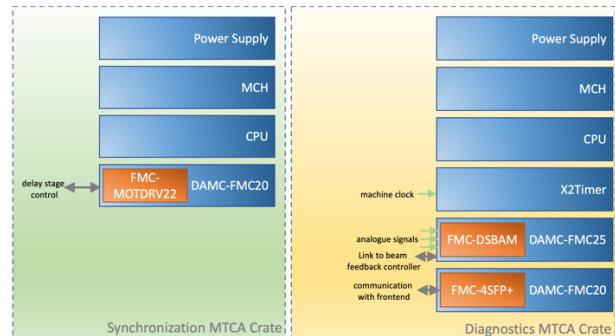


Figure 4: BAM Backend Block Diagram

COMMISSIONING

Charge Dependency and Resolution

For commission a typical THz user setting has been tuned using the SRF Gun. After the overlap of one laser pulse with the beam pickup signal has been found, several position scans have been performed. For this the BAM delay stage was used to shift the laser reference for a defined amount and to read back the modulation. The measurement has been performed for a bunch charge from 30 pC to 192 pC, as shown in Figure 5.

The system shows a very high sensitivity already at low charge. For different charges the steepest slope has been used for a calibration run which lead to a 4th order fit function. The resolution of the BAM system has been acquired by measuring the residual noise of the BAM readout if there is no electron beam signal applied. The resolution of the BAM system has been measured to be 6 fs rms at 192 pC. The resolution decreased with bunch charge to be 13 fs rms at 60 pC.

At 70 pC the signal begins to show overmodulation that means an increase of the modulation voltage does not lead to a further amplitude increase but decreases the signal. This well-known feature leads to ambiguous arrival time measurements if the BAM is operated close to a modulation factor of two or close to zero, which should be avoided. For higher charges the overmodulation is even more pronounced which leads to a reduced dynamic range of the BAM system. While the dynamic range is 12 ps for charge below 70 pC, it is reduced to 4 ps for higher charge.

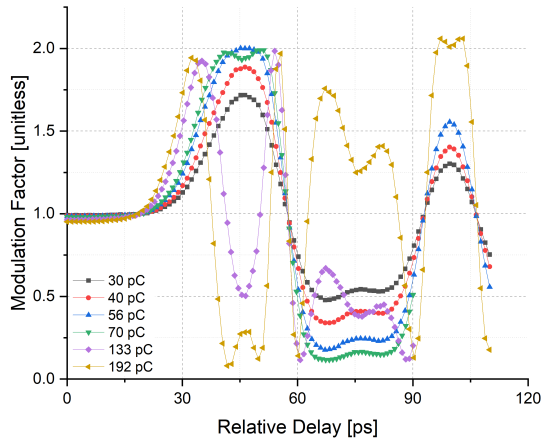


Figure 5: Laser Pulse modulation versus Relative Time Delay for varied Bunch Charge

Machine Studies

The BAM setup has been used to perform arrival time jitter studies for a typical THz user setting operating the machine at 50 kHz and 190 pC. Figure 6 shows the result in time domain and frequency domain. In this example the jitter has been measured to be 65 fs rms in an interval from 1 Hz to 25 kHz. The time domain signal shows random spurious that need to be investigated. In the frequency

domain 50 Hz from the power grid and harmonics can be observed among other frequency components.

The acquired data will serve as a starting point for further machine studies.

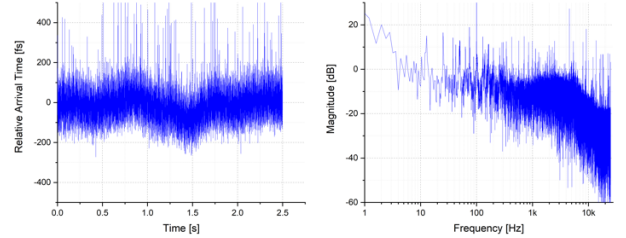


Figure 6: Arrival Time Measurement in Time Domain and Frequency Domain

The BAM data can also serve as input for a beam-based feedback which is actively stabilizing the arrival time by acting on the amplitude and phase of the accelerating modules upstream the bunch compressor chicane [6]. The direct low latency data connection to a dedicated feedback controller was a main driver for the transition to the new BAM hardware.

CONCLUSION AND OUTLOOK

A new BAM system has been commissioned successfully at ELBE which enables high resolution measurements of arrival time. The resolution was measured 6 fs rms at 192 pC bunch charge. The strong modulation response causing the excellent resolution reduces in turn the dynamic range to about 4 ps at higher charge.

The BAM system enables machine studies to understand the source of arrival time jitter and generates the input data for an active arrival time stabilizations.

REFERENCES

- [1] F. Loehl et al., A sub 100 fs electron bunch arrival-time monitor system for FLASH, EPAC2006, Edinburgh, Scotland, THOBF101, <https://accelconf.web.cern.ch/e06/PAPERS/THOBF101.PDF>
- [2] M. Kuntzsch et al., Electron bunch diagnostic at the upgraded ELBE accelerator: status and challenges, IBIC2013, Oxford, United Kingdom, MOBL3, <https://accelconf.web.cern.ch/IBIC2013/papers/mobl3.pdf>
- [3] H. Dinter et al., Prototype of the Improved Electro-Optical Unit for the Bunch Arrival Time Monitors at FLASH and the European XFEL, FEL2015, Daejeon, Korea, TUP049, <https://accelconf.web.cern.ch/FEL2015/papers/tup049.pdf>
- [4] A. Angelovski et al., "High band width pickup design for bunch arrival-time monitors for free-electron laser", Phys. Rev. ST Accel. Beams 15, 112803 (2012).
- [5] G. Varghese, ChimeraTK – A software tool kit for control applications, IPAC2017, Copenhagen, Denmark, TUPIK049, <https://accelconf.web.cern.ch/ipac2017/papers/tupik049.pdf>
- [6] A. Maalberg et al., Status of Beam-Based Feedback Research and Development for Continuous Wave SRF LINAC ELBE. In Proc. 12th Int. Particle Accelerator Conf., Campinas, SP, Brazil, 24–28 May 2021, doi: 10.18429/JACoW-IPAC2021-TUPAB306.