

LONGITUDINAL BUNCH ARRIVAL TIME FEEDBACK AT FLASH

P. Gessler*, M. K. Bock, M. Felber, K. E. Hacker, W. Koprek, F. Ludwig,
H. Schlarb, B. Schmidt, S. Schulz, DESY, Hamburg, Germany

Abstract

After the upgrade of the free electron laser FLASH at DESY electron bunches have a duration of 10 fs to 400 fs and an arrival time jitter of about 100 fs (rms). The newly installed optical synchronization system should stabilize the seed and pump-probe lasers to within 10 fs to the precise optical reference. In order to perform reliable and stable seeding, the electron bunch timing jitter needs to be reduced. Bunch arrival time monitors measure the arrival time fluctuations at different locations and are used in a beam-based feedback loop to correct the amplitude of the accelerator RF. In order to provide reliable operation and high availability of the bunch arrival time feedback, intensive efforts have been undertaken in system automation and exception handling which will be discussed in this paper.

INTRODUCTION

Beam based feedback using bunch arrival time measurements had proven to be an efficient way to increase arrival time stability over a macropulse [1]. However, only if the monitors providing the input data for the feedback running stable and reliable over time a feedback will improve the beam quality and is usable by the operators. The principle of the bunch arrival time monitors (BAMs) used at FLASH is based on an electro-optical detection scheme, where the signal from a wide-bandwidth RF pickup is used to modulate the amplitude of a laser pulse proportional to the arrival time deviation from its expected value. More details on the insights of the optical front-end of this monitor are discussed for example in [2]. These laser pulses are converted into electrical signals, sampled with analog-to-digital converters and processed in specialized electronic hardware which is discussed in [3]. An overview of the longitudinal beam based feedback structure is described in [4]. Here the major influences on the stability, accuracy and reliability related to the bunch arrival time monitor are discussed and possible solutions, information on current implementations and experiences are provided.

CALIBRATION

A typical pick-up signal already processed by the monitor's digital hardware is shown in Fig. 1.

The plot shows the measurement of both the fine and the coarse channel. They rely on the same pickup signals, but

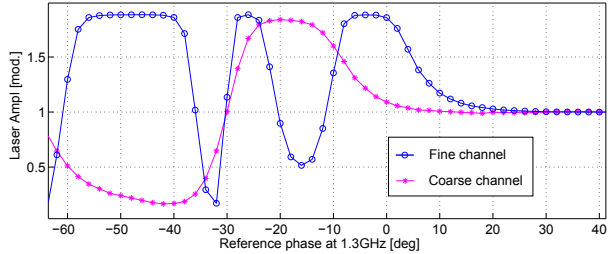


Figure 1: Typical form of fine and coarse measurement of the pick-up signal. This plot has been measured by shifting the phase of the laser pulses step by step relative to the electron bunches and averaging the measured normalized amplitude. Additional dips in the fine signal are due to roll-over effects in the electro-optical modulator (EOM). Flat tops are due to saturation of analog-to-digital converters.

for the coarse measurement it is attenuated before applying it to the electro-optical modulator (EOM). Therefore no roll-over and saturation effects will be created. The coarse measurement has a lower resolution than the fine channel, but it offers a much wider dynamic range. In order to create this plot, the phase of the reference laser pulses were shifted step by step relative to bunches (i.e. the accelerating RF of 1.3GHz).

In this particular case, the working point of the monitor is at a reference phase of -30 deg, where both lines are crossing at a normalized amplitude of one.

In order to calculate the arrival time based on the measured normalized amplitude of the laser pulses a conversion factor has to be determined. This calibration is achieved by varying the reference laser pulse train in a small defined time frame around the working point. During the variation a number of macropulses are measured and using a linear fit, the most likely conversion factor can be calculated. The timing variation of the laser pulse train is achieved by a motorized optical delay stage included in the BAM front-end. Attached to that stage is an absolute position encoder with a resolution of about 5 nm which is used to calculate the time shift.

In calculation of the linear fit, measurement errors has to be taken into account. The largest influence on the measurement are arrival time fluctuations of the electron bunches as well as the amplitude noise of the laser pulse train. The amplitude noise influences the measurement of the amplitude while the arrival time jitter acts on the time variation of the laser pulse train. Therefore the fitting algorithm has to take errors in both coordinates into account [5][6][7]. Although influences on the conversion factor like charge

* patrick.gessler@desy.de

and orbit dependencies could be minimized with compensation factors, the calculation has to be done on a regular basis. The current implementation allows an automatic calibration after a user configurable number of macropulses. It is desirable that the measurement as well as beam based feedbacks based on the arrival time continue during calibration. Therefore, the absolute position of the optical delay stage needs to be known during arrival time measurements to remove the introduced error from the calculations. This requires a synchronized readout of the position encoder of the delay stage. This is currently under development and will be available in the near future.

OPTICAL DELAY STAGE FEEDBACK

As discussed in the previous section, an optical delay stage is included in the BAM front-end to allow to shift the laser pulse train in time relative to the electron bunches. If the mean arrival time of the bunches is changing due to different machine settings, the laser pulses have to be shifted accordingly, in order to reach the optimal working point (see again Fig. 1).

A feedback loop measures the mean normalized amplitude of the modulated laser pulses for a macropulse. If it deviates more than a configurable threshold around one, the delay stage will be adjusted to set it back close to one.

The optical delay stage feedback uses the coarse channel to find the working point after significant changes in the arrival time. The fine channel is used to fine tune the delay around the working point.

In order to align the coarse and the fine channels (which have individual electro-optical modulators), an additional optical delay stage is included in the front-end. The feedback also takes care, that the coarse channel will stay in phase with the fine channel while the working point is kept.

ELECTRO-OPTICAL MODULATOR BIAS VOLTAGE

The component in the BAM front-end to modulate the arrival time information onto the laser pulses is an electro-optical modulator (EOM). The working point of the EOM is adjusted at the bias voltage input that defines the transmission of the laser pulse train, if no RF signal is present. This influences the modulation depth and therefore the shape of the signal in Fig. 1. In order to achieve the best trade-off between resolution, dynamic range, and linearity, the bias voltage needs to be adjusted from time to time on a long term basis to compensate for thermal drifts. An automated approach is not implemented yet, but it is planned in the following way:

1. Disable the optical delay stage feedback.
2. Adjust the delay stage such that the laser amplitude moves to its maximum value (i.e. right of the working point in Fig. 1).

3. Adjust the bias voltage, for the predetermined optimal modulation.
4. Reset the delay stage to its previous position.
5. Enable the optical delay stage feedback.
6. The feedback will readjust to the working point.
7. Recalibration.

POLARIZATION CONTROLLER

The electro-optical modulators are sensitive to the polarization of the input laser pulses. This influences the energy of the output laser pulses and therefore the signal-to-noise ratio of the measurement. Also the pulse form is influenced in the optical to electrical conversion in the sampling and processing hardware [3].

The cause for polarization changes between the EOM input and the far end side of the optical link of the laser pulse source are multiple factors like temperature changes and mechanical stress on the fiber. In normal operation these changes are slow and reajustments every few hours are required.

To compensate for those changes two motorized wave plates (i.e. $\lambda/2$ and $\lambda/4$) are included at the beginning of the link. A feedback loop measures the amplitude of the laser pulses and maximizes them by adjusting the wave plates accordingly.

SAMPLING CLOCK DELAY ADJUSTMENT

In the sampling and processing hardware, the modulated laser pulses are converted to electrical signals and sampled by analog-to-digital converters (ADCs) [3]. A plot of two subsequent laser pulses is shown in Fig. 2.

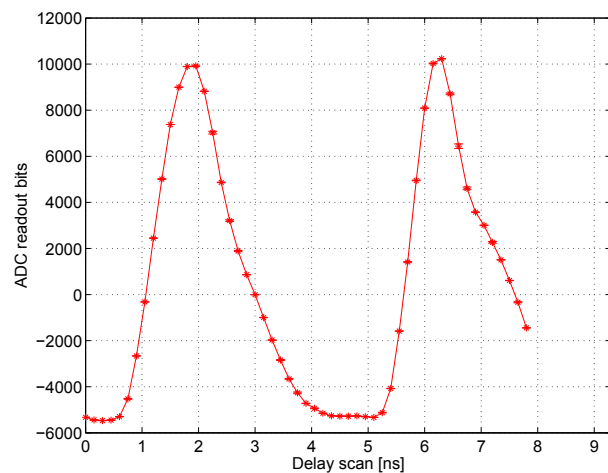


Figure 2: Plot of the laser pulse form, as the ADC will sample it. It was measured by adjusting the sample clock phase step by step and sampling and averaging the converted laser pulses.

One ADC samples the peak and a second ADC the baseline of the signal. Adjustable delay elements are included in the hardware to allow individual clock adjustments of the ADC sampling clock. By that means it is possible to optimize the sampling points for peak and baseline.

Mostly due to temperature changes, the fibers between the BAM front-end and the electronic hardware as well as chips on the electronic hardware could introduce phase shifts between signal and clock. Therefore an automatic sampling clock delay adjustment will be implemented in the future, to automatically compensate for clock or signal phase changes.

CONCLUSION AND OUTLOOK

It has been shown that different automation routines and feedbacks are required to provide reliable data and thus a stable bunch arrival time monitor. Influences due to polarization changes, temperature change induced relative clock shifting, mean arrival time changes, adjustment of modulation depth, and recalibration of the monitor are only the major tasks and were discussed here.

A complex high level error detection and exception handling scheme is currently under development to ensure, that invalid data and conditions are minimized to prevent critical operation states for the machine, if the feedback is active.

Long term measurements will show the stability and operability of the system and reveal additional challenges we might be faced with.

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