Simulations on Beam Monitor Systems for Longitudinal Feedback Schemes at FLASH.

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Outline

1. FLASH Operation in the Past and Present
   - Bunch Compression and Arrival-Time
   - Beam Monitors
   - Demonstration of a Longitudinal Feedback

2. FLASH Operation in the Future
   - Beam Dynamics Simulations
   - Redesign of the BCM

3. Future Longitudinal Feedback
   - Beam-based Feedback Structure
   - Simulations on Contributions: Arrival-Time and Compression
   - Evaluation of Monitor Signals

4. References
**Slow Drifts: Single Bunch Operation.**

RF parameters in front of the magnetic chicanes ⇒ bunch arrival time and compression.

**Figure:** Slow phase feedback. (Logbook print)

**Figure:** Bunch arrival time: RF gun. (Ref.: [1])

Slow beam-based feedback is mandatory.
Fast Variations: Long Bunch Trains.

**Figure:** Lasing with long bunch trains. (Logbook print)

RF phase and amplitude slopes along the train $\Rightarrow$ bunch arrival time and compression.

Fast (intra-bunch-train) beam-based feedback is mandatory.
Bunch Compression Monitor (BCM).

- Coherent diffraction radiation from slitted metallic screens.
- Radiation transport: THz and GHz wavelength range.
- Pyroelectric detectors: LiTaO$_3$ (2 mm $\times$ 2 mm $\times$ 27 $\mu$m).

Figure: Present BCM Setup.

Figure: Left: Diffraction radiator, Right: Pyroelectric sensor.
Bunch Arrival-Time Monitor (BAM) (Ref.: [2,3]).

- Beam pick-up: Signal generation.
- MLO: Reference laser pulse train.
- EOM: Bunch arrival time is encoded in amplitude modulation.

Dynamic ranges: 65 ps (coarse) and 4 ps (fine).
Bunch Arrival-Time and Compression Feedback (Ref.: [2]).

Figure: Arrival-time with amplitude control.

Figure: Phase jitter with phase control.

Feedback on the RF parameters of ACC1 in front of the first magnetic chicane.
Longitudinal Phase Space Simulation

Details of the Simulation

- Transformation of the longitudinal phase space.
- Longitudinal space charge (LS).
- Cryo module wake fields ($W_1$ and $W_3$).
- Wake fields due to coherent synchrotron radiation ($W_{in}$ and $W_{out}$).

- BAM implementation: centroid shifts w.r.t to a reference.
- BCM implementation: DR spectrum (single electron and transport optics), form factor (bunch), detector response (pyro).
Benchmark: Phase Scan of ACC1.

ACC1 phase scan around maximum compression (without third-harmonic RF cavity). This scan is useful to find the FEL operation phase.

- BCM can basically be described by the DR spectrum and the form factor.
BCM Response for Linearized Compression.

Wavelengths contributions to the BCM signal for different compression schemes.

Strategies to improve BCM signals.
- Redesign of the BCM setup ⇒ be more sensitive at long wavelengths.
- Another working point ⇒ shift form factor to shorter wavelengths.
- A different detector technology ⇒ e.g. antennas in the GHz range.
Future BCM Setup (Ref.: [4]).

- Two detectors in order to increase the dynamic range.
- Coarse: Find operation points (e.g. by phase scans).
- Fine: Stabilization by feedbacks.

Simulation (THzTransport)

- Diffraction radiation of a single electron.
- Source geometry (slitted metallic screen), port window and transport optics.
Planned Feedback Structure

Arrival-Time Jitter Behind Magnetic Chicane

\[ \sigma^2_t = \left( \frac{R_{56}}{c_0} \frac{\sigma_A}{A} \right)^2 + \left( \frac{C - 1}{C} \right)^2 \left( \frac{\sigma_\phi}{c_0 k_{RF}} \right)^2 + \left( \frac{1}{C} \right)^2 \sigma^2_{t, initial} \]

Intra-bunch Train Beam-based Feedback

- Optical cross-correlation (OCC): Correction of laser phase. (talk of S. Schulz)
- BAM (in front of 1st BC): Correction of gun phase.
- BAM and BCM (behind 1st BC): Correction of phase/amplitude of ACC1 and ACC39.
- BAM and BCM (behind 2nd BC): Correction of phase/amplitude of ACC2/3.
Contributions from the Injector: OCC and BAM (Ref.: [1,2]).

Simulations: Injector

\[ \Delta t_{\text{beam}} \approx G_{\text{laser}} \Delta t_{\text{laser}} + G_{\text{gun}} \Delta t_{\text{gun}} \]

\[ \Delta t_{\text{laser}} = \frac{\Delta \phi_{\text{laser}}}{\omega_{\text{RF}}} \]

\[ \Delta t_{\text{gun}} = \frac{\Delta \phi_{\text{gun}}}{\omega_{\text{RF}}} \]

Measurements: Injector

- Laser phase: 1.45 ps \(\Rightarrow\) 68%
- Gun phase: 0.68 ps \(\Rightarrow\) 32%
- Good agreement with simulations.

- OCC: Correction of laser phase.
- BAM: Correction of gun phase.
Contributions from ACC1 and ACC39: BAM and BCM.

Variation of the RF amplitudes/phases by $\pm 1\%$/deg around the proposed working points.

- **BAM**: ACC1 has largest impact with both phase and amplitude.
- **BCM**: Phases of ACC1 and ACC39 have strongest influence.

Sensitivities of BCM/BAM on RF parameters depend on the working point $\Rightarrow$ reduce sensitivity by convenient working points (e.g. on-crest operation).
Future Longitudinal Feedback
Evaluation of Monitor Signals

Linear Map: Monitors and Actuators (Example: 1st BC).

Monitors

\[ M = \begin{pmatrix} \Delta t_{BAM} \\ \Delta C_{BCM} \end{pmatrix} \]

Sensitivities (Jacobian matrix)

\[ S = \begin{pmatrix} \frac{\partial A_1}{\partial A_1} & \frac{\partial A_1}{\partial \Phi_1} & \frac{\partial A_{39}}{\partial A_1} & \frac{\partial A_{39}}{\partial \Phi_1} \\ \frac{\partial \Phi_1}{\partial A_1} & \frac{\partial \Phi_1}{\partial \Phi_1} & \frac{\partial \Phi_{39}}{\partial A_1} & \frac{\partial \Phi_{39}}{\partial \Phi_1} \\ \frac{\partial A_{39}}{\partial A_1} & \frac{\partial A_{39}}{\partial \Phi_1} & \frac{\partial A_{39}}{\partial A_{39}} & \frac{\partial A_{39}}{\partial \Phi_{39}} \\ \frac{\partial \Phi_{39}}{\partial A_1} & \frac{\partial \Phi_{39}}{\partial \Phi_1} & \frac{\partial \Phi_{39}}{\partial A_{39}} & \frac{\partial \Phi_{39}}{\partial \Phi_{39}} \end{pmatrix} \]

Actuators

\[ A = \begin{pmatrix} \Delta A_1 \\ \Delta \Phi_1 \\ \Delta A_{39} \\ \Delta \Phi_{39} \end{pmatrix} \]

Linear Map Between Monitors and Actuators

\[ M = S \cdot A \Rightarrow \text{matrix inversion by sophisticated methods.} \]
### Summarized Notes

#### Beam-based RF Phase and Amplitude Control at FLASH
- Important to reduce slow drifts and variations along bunch trains.
- Phase: Bunch Compression Monitors.
- Amplitude: Bunch Arrival-Time Monitors.

#### Combined Beam Dynamics and Diagnostics Simulations
- Useful to predict applicability of diagnostics for different operations (e.g. different compression schemes).
- Is able to provide recommendations or even constraints on the working point definition.
- Studies on sensitivities of monitors for beam-based feedbacks are possible.
The End.

Thank you for your attention!
References used in this Presentation


