Requirements and status of PETRA IV Fast Orbit Feedback System

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Abstract
PETRA IV is the upcoming low-emittance, 6 GeV fourth-generation light source at DESY Hamburg. It is based upon a six-bend achromatic lattice with additional beams as compared to PETRA III. A stringent stability of the electron beam orbit in the ring will be required to achieve a diffraction-limited photon beam quality. In this regard, the requirements and the proposed topology of the global orbit feedback system are discussed for expected perturbations. An initial analysis based upon system requirements, design and modelling of the subsystems of the orbit feedback system is also presented.

Proposed topology
- Orbit correction for the full range of disturbance spectrum, i.e. from quasi-DC to high frequency (1 kHz).
- 788 beam position monitors (BPMs) and 322 vertical and 200 horizontal fast correctors.
- Extended star topology (latency optimized) having 15 local nodes (LOC) and 1 global central node marked as GLO.
- BPM crates and power supplies (PS) racks to be the peripheral nodes for each local star.
- BPMs in the MicroTCA 4 form factor, housing multiple BPM processors coupled with a data aggregation AMC for transferring the corresponding BPM data to LOC.
- PS units to be distributed into racks with a single optical link per rack.
- The GLO and LOC to have similar hardware of MicroTCA 4 form factor.
- GLO will have bilateral optical links up to 1.2 km long with all 15 LOCs. Each LOC will have optical links with the local BPM crates and local PS racks.
- Optical links to both neighboring LOCs (upstream and downstream) and experimental stations.
- Data propagation within the MicroTCA 4 backplanes is latency-optimized of the order of 270 ns, while the optical cable paths are latency-optimized.
- Data transfer times are up to 6 µs for the longest communication path between LOC and GLO, and expected latency of less than one microsecond for each local communication, i.e. LOC to PS and BPM.

Analytical modelling of subsystems
BPMs
BPM electronics is based on Libera Brilliance® system providing turn-by-turn data with a resolution of at least 100 nm and an update rate of 130 kHz. A maximum latency of 3 turns, i.e. 23 µs.

Cable and corrector magnets
At 3 horizontal and 2 out of 4 vertical fast correctors per cell (in the superlattice of PETRA IV) overlap the locations of slow correctors. For the combined ACR/GLO corrector magnet design is proposed capable of 800 µrad DC deflection and 30 µrad integrated deflection (up to 1 kHz). The aperture diameter of 26 mm and length no longer than 150 mm are the design parameters from the lattice point-of-view. The proposed design is based on the layout of the ACR corrector magnet for APS-U. This layout allows improved field quality for both deflection planes, created by the main and auxiliary coils. Cables with lengths up to 200 m are required between the corrector power supplies and the magnets to keep the power electronics outside the tunnel. This puts special demands on the cable itself, like low losses, radiation hardness and cable-magnet resonance. A notch at 8.3 kHz is observed in simulations in the source current. Hence, a notch creates an uncertainty between source and magnet current in frequencies around notch. Hence, a 8.3 kHz notch is present in the drive circuit. The notch in current is in the cooled cable connected with magnet coil, at 3.3 kHz due to the source point of view.

Corrector power supply
Design not finalized yet, but the considered option includes two paths: slow regulation (feedback based) up to a maximum of a few hundred Hz for mainly slow drift compensation and fast uncontrolled (feed-forward) action for fast corrector to overcome mismatch in the current readback using DCCT at PS output. This solution provides low latency, the update rate of 130 MHz, no feedback but a lead-lag component is required for the fast corrector coil to reach at least 1.3 kHz open-loop BW.

Vacuum chamber
A low-pass filter behavior attenuating the magnetic field inside the chamber. If the skin depth of material is larger than the thickness of the chamber, its response can be modelled as a first order filter. 1 mm thick stainless steel chamber of radius 6 mm (BW=8.8 kHz, contrary to the alternate option of copper (BW=770 Hz, for 0.5 mm thickness). Remark: inner coating ignored yet.

Summary and outlook
In this paper, a preliminary analysis of requirements and proposed topology for global feedback system for PETRA IV is presented. Analytical subsystem modeling is also presented in order to evaluate the feasibility 1 Hz disturbance rejection bandwidth. The interaction of feedback system with the synchrotron oscillations shall be studied as a next step.

SISO simulation
A first-hand estimation of the full-loop transfer function and delay budget is made for the longest path from LOC to GLO stations. An open-loop BW of 1.26 kHz and a delay of 83 µs (tZPA = 23 µs, tZPAatts = 30 µs, τZPA-corr = 15 µs, τZPA-corr = 15 µs).

Betatron oscillations
The update rate for FOB system = 130 kHz. Betatron frequencies vs = 23.43 kHz and ωp = 35.16 kHz need to be included into modeling. The transfer function for Betatron excitation is:

\[ \text{Betatron excitation} = \frac{1}{\tau} \text{Betatron oscillations} = \frac{1}{\tau} \left( \frac{\tau}{\omega_p} - \frac{\omega_p}{\tau} \right) \]

with narrow-bandwidth, i.e. in the bandwidth of PETRA IV FOB system. 0 Hz
But not included in these simulations.

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