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Baseline system specifications for LE storage ring commissioning

Beam Tests and Commissioning of Low Emittance Storage Rings, 02/18/19

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Stages of Commissioning

5 phases of commissioning can be identified:

- Phase 0: before commissioning (time of final system installation and alignment)

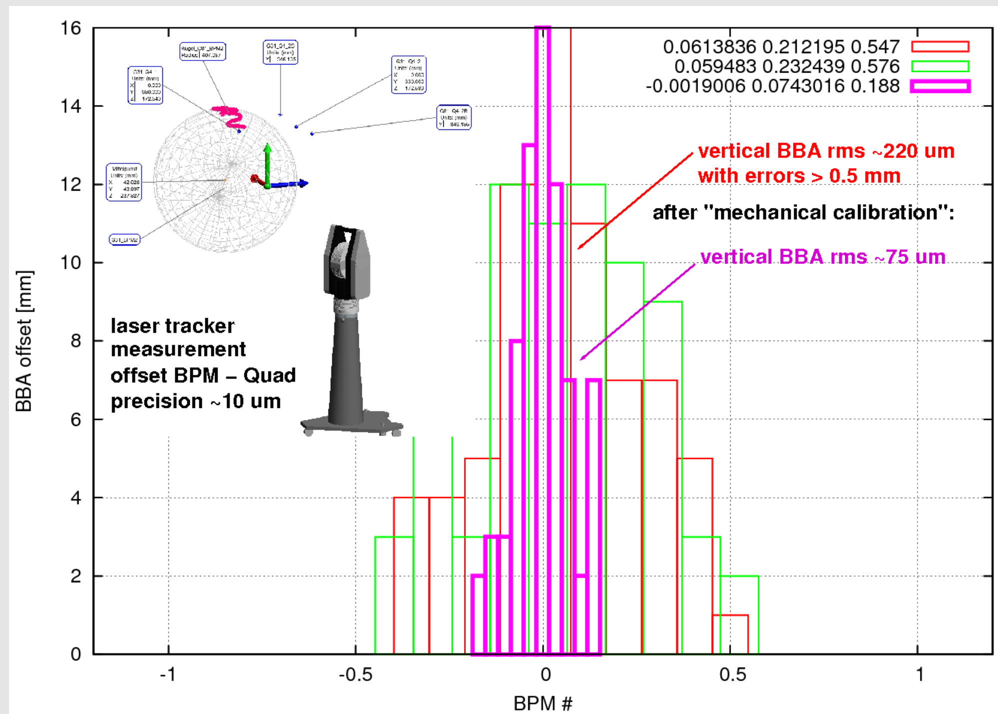
- Phase 1: injection into the LE ring / getting stored beam
- Phase 2: characterization of the LE ring using stored beam at low current → realignment to optimize the alignment error distribution in favour of machine performance
- Phase 3: commissioning with multi-bunch filling and high current
- Phase 4: commissioning of systems vital for user operation (Fast Orbit Feedback) running at design parameters

- Phase 5: after commissiong (insertion device and beamline commissioning) and finally operation with friendly users

Stages of Commissioning: Phase 0

Phase 0: before commissioning (time of final system installation and alignment)

- One main prerequisite for going through phase 1 is a LE ring within specifications (magnets and alignment, correct cabeling) ! SLS 2.0 alignment errors: girders 60 um, girder-girder 20 um, element-element 30 um rms.
  Measurement of BPM to Quadrupole offsets after final alignment !
  In the SLS a ~220 um rms vertical BBA offset could be
- reduced by a factor 3 by measuring the mechanical contribution in the tunnel.
  Electronic contributions can be minimized by using a pilot signal for calibration of the BPM electronics or even using the entire analogue signal path.
  → BBA errors ~ girder errors



Stages of Commissioning: Phase 2

Phase 0: Before commissiong (time of final system installation and alignment)

- Check of the correct polarity of all magnets and search for forgotten or wrong magnet cabeling

Phase 1: injection into the LE ring / getting stored beam

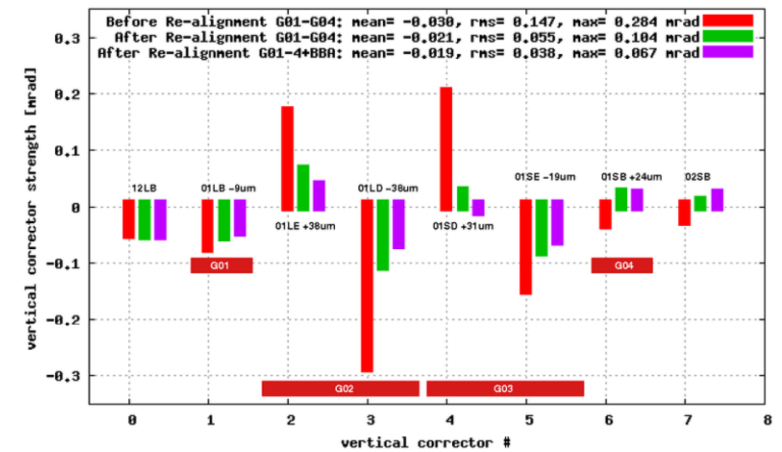
- If some beam can be stored (magnets ok, dynamic aperture for injection ok, (+-6mm in SLS 2.0 case) alignment ok) characterization and correction of the LE ring optics, BBA and orbit correction can be immediately done → Phase 2

- If NOT ... triggered BPMs with single / multi-turn capability with high (~MHz) bandwidth and moderate resolution ~10 um are needed for injection studies and to thread the beam around the ring to get a closed orbit. BPM to quadrupole / sextupole offsets (SLS 2.0: 120 BPMs and 120 dedicated BBA quads) can be determined without having a closed orbit by applying linac based BBA concepts in order to reduce the offset errors to a few ten um. Crude optics measurement could also be carried to identify large optics errors → hopefully stored beam ...

Stages of Commissioning: Phase 2

Phase 2: characterization of the LE ring using stored beam at low current (single bunch <1mA)

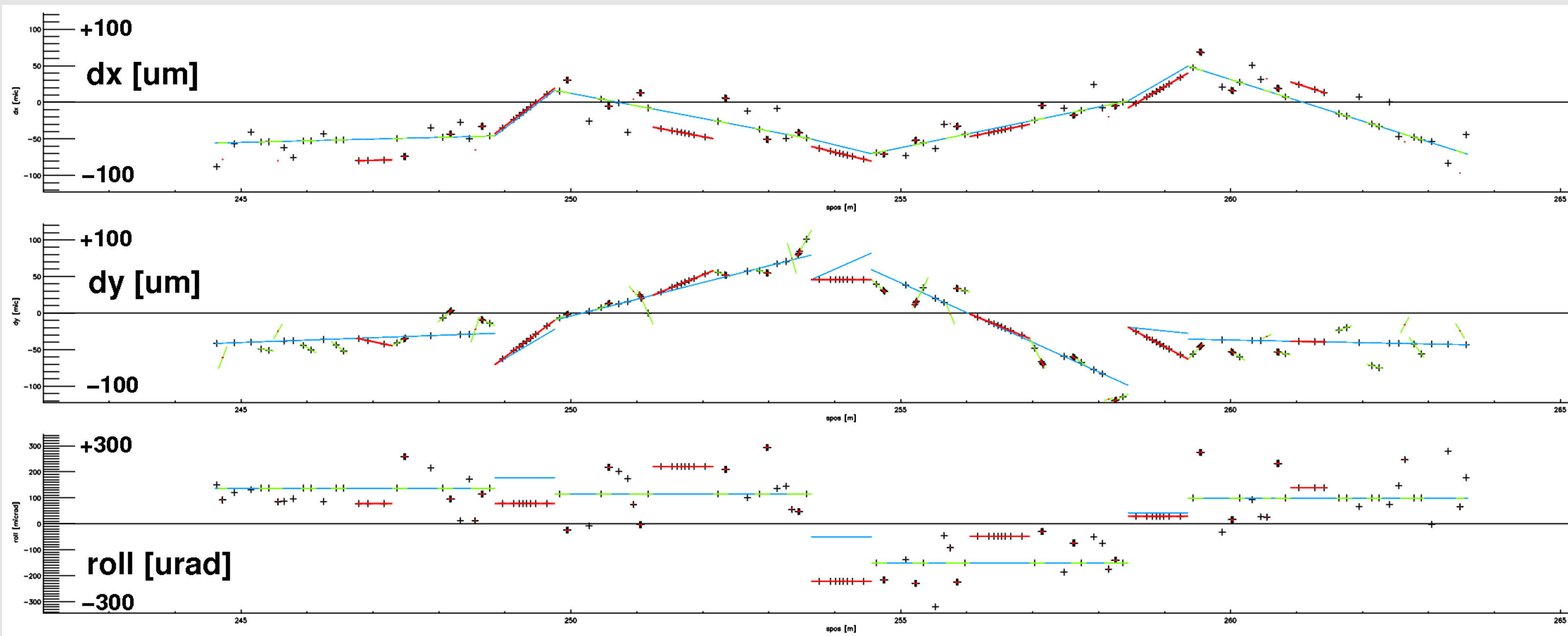
- High precision (~1 um) BBA and successive orbit correction to BPM centers using ALL orbit correctors (no eigenvalue cut) in order to LOCALIZE alignment errors !
- Girder realignment of the LE ring to optimize the alignment error distribution in favour of machine performance and minimize the needed orbit corrector strength ! In the SLS all 48 girders have been used to reduce the total
- rms vertical corrector kick from 150 to 50 urad (see example for 4 girders). Remotely controlled girders can speed up this realignment since it can be done with stored beam and directly verified by observing the reduction of corrector strength (SLS 2.0 48 remotely controlled girders +-500 um for pitch/heave, 96 actuators for girder based correction)

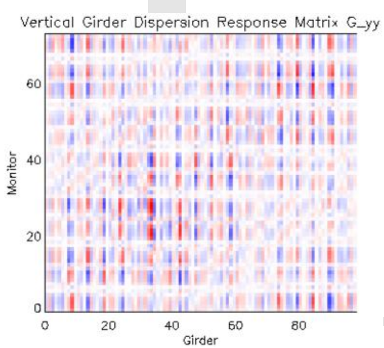


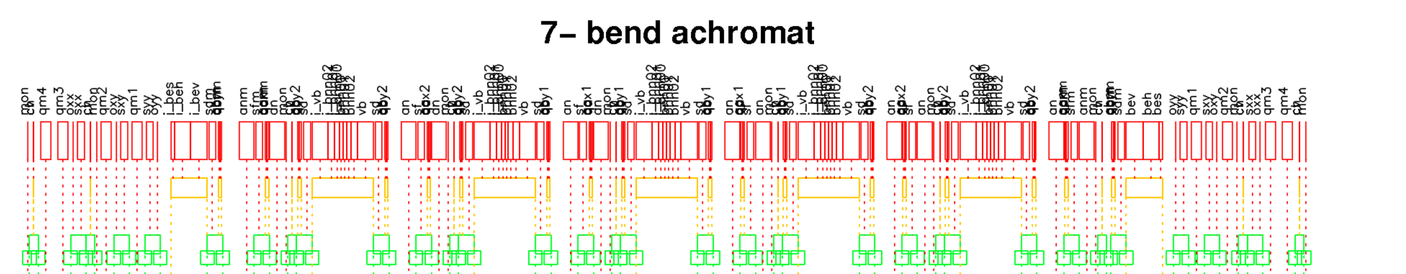
Corrector strengths before and after girder realignment, and after beam based BPM calibration* (sector 1)
(*girder move causes vacuum chamber deformation)
⇒ Factor ≈4 reduction of rms CV kick in sector (= 4 girders)

Stages of Commissioning: Phase 2

- For illustration one of 12 7-bend achromats in SLS 2.0 with girder/element errors within specification (girder 60um, girder-girder 20um, element-element 30um):







Stages of Commissioning: Phase 2

Phase 2: characterization of the LE ring using stored beam at low current (single bunch <1mA)

- Tune measurement (using single or many BPMs, FFT, Naff, Model Independent Analysis (MIA))
- Average beta function measurement in quadrupoles (SLS 2.0: 288 dedicated quadrupoles for optics measurements, tune variation and BBA) using high precision tune measurements
- Optics studies measuring phases (linear and nonlinear with help of pinger magnets)
- Measurements of amplitude dependent tune shifts (frequency maps) → optimization of higher order correction multipoles (SLS 2.0: 288 octupoles)
- LOCO (Linear Optics from Closed Orbits) based on BPM / corrector response matrices (→ correct linear optics further and eventually adapt optics model)
- Betatron coupling / dispersion minimization with dedicated skew quadrupoles (SLS 2.0: 288 skew quads) → after adjustment of desired emittance coupling in order to optimize lifetime (dispersion bump, betatron coupling)
- Orbit Feedback (~ Hz) for orbit standardization (zero orbit = golden orbit)

Stages of Commissioning: Phase 3

Phase 3: commissioning with multi-bunch filling and high current

- Filling pattern measurement and commissioning of FP feedback
- Top-up operation by doing frequent injections with small single bunch currents
- Commissioning of multi-bunch feedbacks
- Harmonic cavity tuning for bunch lenghtening → lifetime improvement
- Longitudinal bunch profile characterization with streak camera
- Orbit noise identification with BPMs running in narrow bandwidth (a few kHz) mode (power spectral densities) → preferably noise suppression by source suppression
- Final commissioning of the BPM system for preparation of first Fast Orbit Feedback operation
- Commissioning of the first photon monitors (PBPMs)
- Measurement of open loop transfer functions of fast correctors (SLS 2.0: 120 individual slow/fast combined correctors with a maximum strength of +-400 urad and a resolution of ~ 1-2 nrad) → determine bandwidth limitations of the correction system

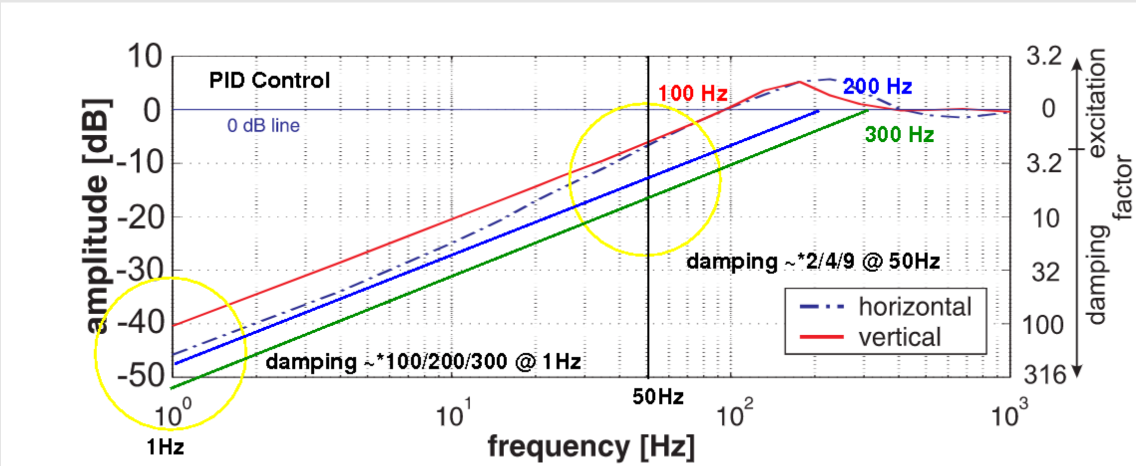
Stages of Commissioning: Phase 4

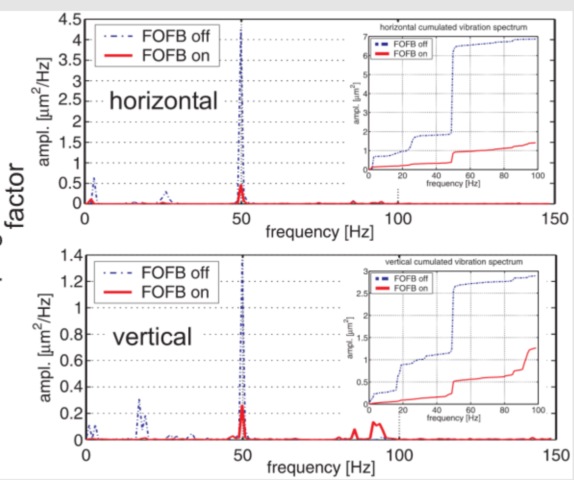
Phase 4: commissioning of systems vital for user operation (Fast Orbit Feedback) running at design parameters → FOFB specifications:

- Correction up to >100 Hz (0 dB point) → a few kHz BPM bandwidth

USED FOR:

- Suppression of all ID induced orbit distortions (~typically a few Hz, transparent ID operation)
- Suppression of residual noise (typically LS have <1um orbit stability !)
- Reference orbit manipulations for ID's (angle and position of e-beam in ID center, depending on the corrector/BPM response matrix → preferably each BPM has adjacent corrector → correction into integrated BPM noise <0.1 um up to 0 dB point





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Stages of Commissioning: Phase 4

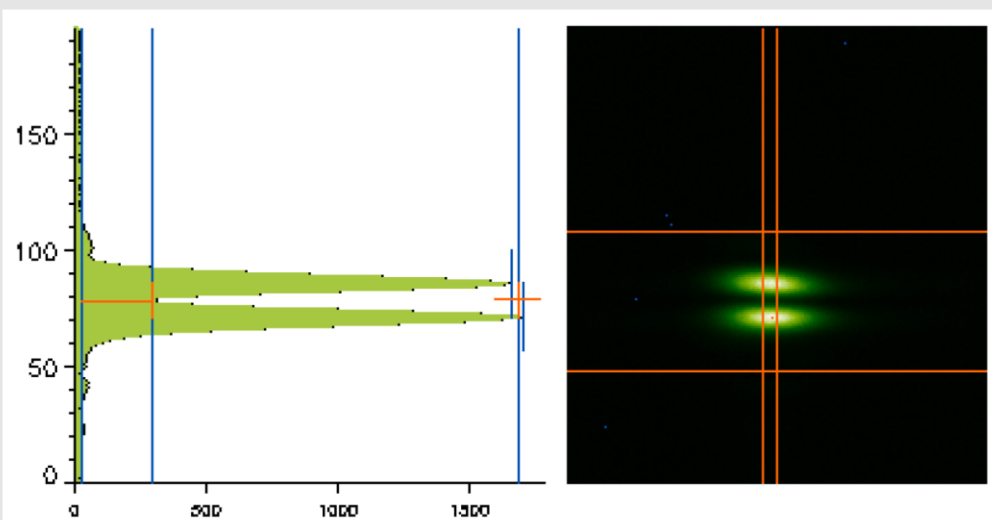
- Demands for Fast Orbit Feedbacks (FOFBs)

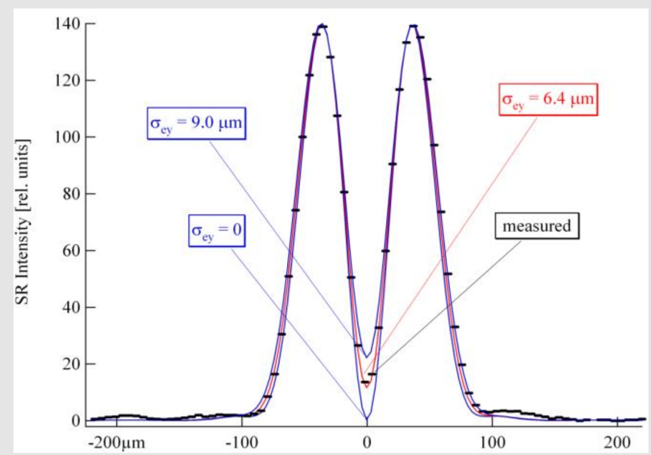
- Very high availability (<1 failure / week, No FOFB = No Beam for users)
- Self diagnosis and „self repair“ features (automatic re-initialization in case of faulty BPM/corrector hardware (response matrix changes) and/or BPM despiking by replacement with „virtual“ BPMs based on machine model)
- Correction limitation/band to avoid FOFB induced beam losses (adaptive)
- Post mortem analysis after FOFB failure and archiving of FOFB activity
- Use of model based response matrix preferable (measured should be possible)
- Automatic adaption of used response matrix to machine optics changes
- BPM weigthing (BPMs next to ID‘s important) , corrector kick constraints, eigenvalue cuts for „longer range“ corrections and BPM noise reduction
- Extra suppression/filters of dominant lines in noise spectrum (mains @ 50Hz)
- Feed Forwards for systematic / known distortions (ID movement, orbit bumps with known kick ratio).
- Integration of PBPMs for increased photon beam stability (→ FOFB Interface)
- Radio frequency control for pathlength corrections (energy stabilization)
- Special measurement features (Beam-Based Alignment, BPM rotation measurement with closed orbit bumps)

Stages of Commissioning: Phase 4

- More demands for Fast Orbit Feedbacks (FOFBs)
- Integration of other magnets like skew quadrupoles for coupling / lifetime feedbacks or feed-forwards for systematic / known coupling changes (orbit bumps, vertical emittance control through dispersion or betatron coupling „bumps“
- Integration of other diagnostics like beam size (emittance) monitors for fast emittance stabilization (2nd order orbit control) utilizing skew quadrupoles as actuators

Emittance monitor at SLS to be reused at SLS 2.0:





Stages of Commissioning: Phase 5

Phase 5: after commissiong (insertion device (ID) and beamline commissioning) and finally operation with friendly users

- Creation of ID Feed Forward tables keeping photon beam stable during ID operation
- Correction of local beta beat induced by ID operation (tune stabilization)
- Operation of a fast (~Hz) tune feedback acting on tuning quadrupoles.
- PBPM based photon position feedbacks to stabilize the photon beam in the beam lines on the sample (sacrifice electron orbit stability !)

- Operation with friendly users (close collaboration between machine and beam line in order to achieve the ultimate beam stability)

- Consolidation of procedures in order to allow for 24/7 beam operation, fast machine setup and refilling

finished

- Phase 1 is most critical for LE rings
- Perfect correction of the LE ring optics is the prerequisite to achieve design performance
- Multi-bunch instabilities need to be cured for high current operation
- NO QUANTUM STEPS NECESSARY for successful and FAST commissioning of LE rings :-)