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Some Considerations on First Turn(s) Dedicated Diagnostics for LE Storage Rings

ARIES WS on Beam Tests and Commissioning of LESR, KIT Feb 18th – 20th 2019

Acknowledgements 😀 😘 😀

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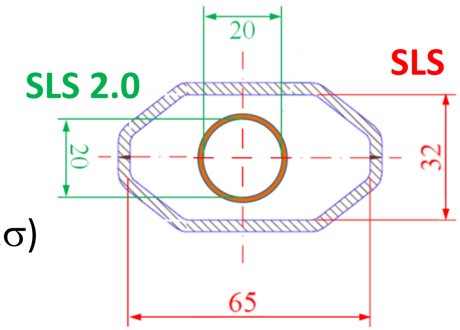
… many more discussions before and during this workshop

Motivation: from 3rd Gen. → DL Light Sources

Challenges for injection into a low emittance storage ring (DLSR)

… strongly reduced **vacuum chamber dimensions**

→ smaller dynamic aperture for ideal machine / lattices



… much smaller **dynamic aperture** for **“real” machines / lattices**

→ with specified (best case!) alignment errors of e.g. < 30 μm (2σ)

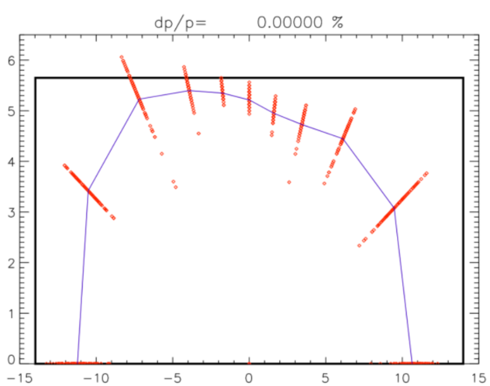
… even smaller **dynamic aperture** for **“realistic” machines / lattices**

→ considering realistic (even worst case!) alignment errors and off-energy particles

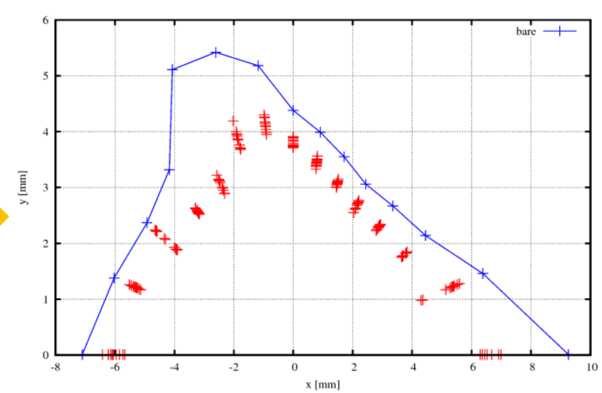
… **beam quality of injector** (booster synchrotron) and **stability of injection elements**

→ booster remains unchanged for most upgrades (large emittances: 2 to > 100 nmrad!)

→ pulsed extraction / injection elements (kicker & septa) may jitter and drift considerably



dynamic aperture shrinks by a factor of 2 from SLS to SLS 2.0



courtesy of Michael Böge, PSI

Motivation: Preparation of Diagnostics Systems

Pre-requisites for injection into a low emittance storage ring
(related to diagnostics)

<u>Alignment Tolerances / Re-Alignment of Storage Ring</u>

… initial alignment of magnets and girders must be excellent e.g. $< 30\ \mu m$ (2σ)

… alignment of BPM pick-ups should even be more accurate in respect to sextupoles for BBA

<u>However</u>: re-alignment of storage ring might be necessary at an early stage (during commissioning)

<u>Preparation of Diagnostics Systems (e.g. BPMs)</u>

… mature RF feedthrough and pick-up designs (mainly BPMs) to avoid unwanted error sources

… proper choice of cables (same length) and correct cabling of BPM pick-ups (e.g. color coding)

… pre-beam calibration of BPMs (e.g. electronics in lab and with pilot tone in-situ)

… online integrity check of diagnostics signals e.g. with SW-tools (or "BPM expert mode")

Well calibrated and operational BPMs or diagnostics systems should be available to support beam commissioning and not the other way around !!!

(Winnie Decking, EXFEL)

Motivation: Injector and Transfer Line

What can be done prior to injection into a LE storage ring?

Booster Synchrotron Diagnostics

… orbit measurement, monitoring and control → possibly orbit feedback in booster

… beam loss monitoring (at least) around extraction elements

… monitoring of booster extraction (and storage ring injection) elements – mainly for drifts

Booster-to-Ring Diagnostics

… beam position measurements and orbit control / stabilization

… beam emittance and Twiss parameter measurement from booster
(quad scans and one screen or four screens with proper phase advance)

… online beam profile / emittance monitoring e.g. with SR monitor or wire scanner

… beam charge and beam loss monitors to determine transfer efficiency (booster to ring)

… possibly collimation of beam from booster in case of large emittances

First Turn(s) Storage Ring Diagnostics

The "Working Horse": Beam Position Monitors

- **a "first turn" / "turn-by-turn" measurement mode is required**

- **the sum-signal from all four bottoms ($I_A + I_B + I_C + I_D$) provides a relative current / transmission measurement at the BPM locations around the ring**

  → optimization of injection settings and observation of losses (first turn)

  → beam threading for first turn(s)

- **beam position and first turn(s) orbit measurement with sufficient data buffer should be available**

  → "first turn(s)" orbit application for (manual) corrections and identification of aperture restrictions or "unhealthy" BPM readings

  → keep in mind: large offsets (millimeters) in small aperture BPMs may lead to false position readings and corrupt orbit corrections due to non-linearity

First Turn(s) Storage Ring Diagnostics

The "Working Horse": Beam Position Monitors (cont.)

- **first turn(s) / initial BPM readings may only provide a limited accuracy of a few hundred μm (rms)…:**
  - → initial alignment errors: few tens of μm (rms !)
  - → displacements of feedthroughs in BPM PUs lead to offsets and non-linearity (bench-calibration of every BPM pick-up is usually not practical)
  - → differences in cable attenuation (electrical offsets – can be measured)
  - → lab (pre-beam) calibration of electronics in the order of hundred(s) of μm
  - → limited first turn / turn-by-turn resolution in the order of 50 – 100 μm

- **if beam can be kept in the storage ring for hundreds of turns (looking at the BPM sum signal buffer), RF phases can be adjusted → stored beam**

- **tunes can be measured and adjusted with BPM position readings from first tens to hundreds of turns → stored beam**

- **beam-based alignment and optics measurement can be done with stored beam**

The "Working Horse": Beam Position Monitors (cont.)

"First Turn" / Turn-by-Turn BPM Specifications

- operation mode:	first turn / turn-by-turn (e.g. for SLS 2.0: 500 kHz BW)
- beam current (charge):	~ 10 μA (10 pC) – 1 mA (1 nC) (e.g. SLS / SLS-2.0)
- position noise:	< 50 μm – 1 μm (rms)
- position drift:	not important for first turns
- data buffer depth:	> 8'000 turns (x, y and intensity)
- linearity correction:	for large beam offsets (e.g. polynomial correction)
- alignment tolerance:	20 μm (rms) / 5 μm (rms) to adjacent sextupole
- pre-calibration:	QC procedures for feedthroughs and pick-ups possibly test bench measurements lab calibration for electronics / in-situ with pilot tone (hundreds of μm / best case tens of μm)
- validity checks:	with automated SW-tools or BPM expert modes

a comprehensive overview on state-of-the-art BPM systems can be found under…:

https://indico.cern.ch/event/743699/ (ARIES WS Barcelona, 2018)

The "Life Insurances": Beam Loss Monitors

- **beam loss monitoring from the booster extraction point to the end of the storage ring injection straight**

  → e.g. long Cerenkov fiber may cover 100 m with ~ 0.5 m spatial resolution

  → BLMs may provide larger sensitivity and dynamic range than BPMs

  → a redundant system helps debugging in case of failures / emergencies

- **distributed loss monitors around the storage ring provide overall loss pattern**

  → e.g. scintillators + PMT + digitization (commercialized solutions exist ☺)

  → fast loss detection for first turns and turn-by-turn required

  → sufficiently large data buffers for observation of loss pattern

  → loss integral (dose rate monitoring) to localize aperture restrictions (important for "re-commissioning" after ID installations)

  → CS interface to program thresholds for alarms and machine interlocks

First Turn(s) Storage Ring Diagnostics

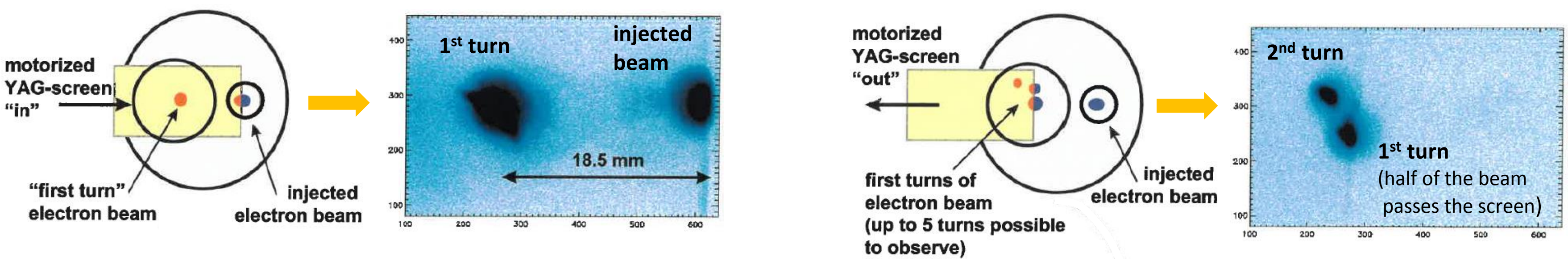
The "Life Insurances": Screen(s) or SR-Monitor(s)

- screens **are** not popular **or** widely used **in storage rings** (impedance, stored beam)

- first turn(s) **during commissioning can be considered as** transfer line diagnostics

  → one screen directly behind injection septum can helpful for observing beam position (relative to septum), beam matching and injection point

  → a second screen in injection straight to adjust the kick / injection angle



- **a** synchrotron radiation monitor **for** visible radiation **can be helpful to observe the first turn(s) and is anyway required for…:**

  → filling pattern and streak camera measurements

  → profile / emittance monitors (π-polarization and interference methods)

Current Monitors and Transmission Measurements

- transmission **from injector (booster synchrotron) into storage ring can be determined (and monitored) with…:**

  → current transformers in the booster synchrotron and storage ring
  e.g. NPCT: 5 (1) μA/$\sqrt{}$Hz from DC (storage ring) to 10 kHz (booster ramp)

  → charge monitors in the booster-to-ring transfer line (at injection rates)
  e.g. ICT / BCM-IHR: < 10 pC – 1 nC (for single bunches or macro-pulses)

- **absolute calibrated charge / current monitors can be used to cross-calibrate BPM sum-signals**

- **real-time determination of transmission efficiency might be required for commissioning and top-up operation**

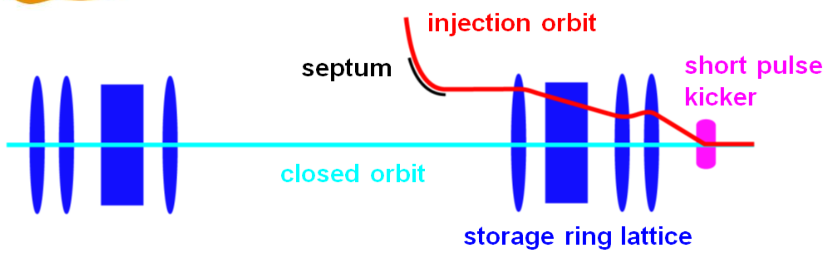
- **Redundant diagnostics systems for machine commissioning** (and top-up operation)**:**

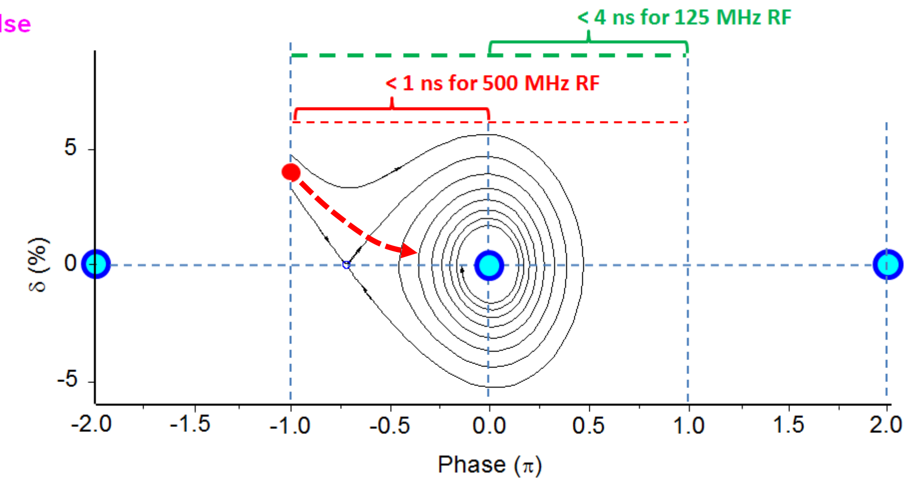
  → **BPMs, BLMs and current (charge) monitors**

First Turn(s) Storage Ring Diagnostics

Diagnostics for "On-Axis" Longitudinal Injection

courtesy of Masamitsu Aiba, PSI





- **injected bunch from booster at slightly higher energy**
  - ⟶ no injection bump: undisturbed stored beam ☺
  - ⟶ injected bunch damps longitudinally in RF bucket due to radiation loss

- **fast kicker with sufficient kick angle is required** ☹
  - ⟶ **~ mrad** within **< 1 ns** (for $RF_{@SLS\ 2.0}$ of 500 MHz) / **< 4 ns** (for $RF_{@SLS\ 2.0}$ of 125 MHz)

Diagnostics for "On-Axis" Longitudinal Injection

- **Option-1** (baseline)**: transmission measurement**

  → use of current (charge) monitors from booster (BTR transfer line) and storage ring

  → provides only "integral information" about injection efficiency but no dynamics

- **Option-2: dual sweep synchro-scan streak camera or dissector**

  → requires dual sweep option

  slow axis: μs (turns) to ms (damping)

  fast axis: < 2 ps is sufficient

  → low intensity from injected bunch requires optimized transfer line design for visible light

  → top-up injections may require pulse picker (injected bunch) and attenuation (stored beam)

- **Option-3: (longitudinal) multi bunch feedback**

  → requires high bandwidth RF front end to resolve damping of injected bunch

  → requires fast (and low latency) ADC for injection between bunches @ 500 MHz

  → requires high dynamic as injected bunch may provide only 10% of stored beam signal

Profile and Emittance Monitors

- **DL storage ring lattices require the measurement / monitoring of horizontal and vertical beam sizes of the order of ≤ 5 μm (1-sigma) @ 10 % coupling**

- **high resolution profile / emittance monitors are already required during commissioning to verify the storage ring lattice (horizontal plane) and to adjust / control the coupling (vertical plane)**

  → low SR light intensity during early commissioning stages

  → larger (vertical) beam sizes possible before lattice / coupling optimization

- **coupling feedbacks based on profile measurements might be required to allow stable user operation with desired beam lifetimes**

- **a comprehensive overview on state-of-the-art profile / emittance monitors for low emittance storage rings and DL light source upgrade projects were presented at an ARIES WS at ALBA, Barcelona (2018) and can be found under…:**

  https://indico.cells.es/indico/event/128/overview

Summary and Some Conclusions

- Most of the diagnostics systems for low emittance storage rings (DL light source upgrade projects) already exists – even with sufficient performance ☺ ☺ ☺
- Proper design strategies for diagnostics systems including alignment, QC and (lab and in-situ) calibration techniques must be developed to provide well understood and useful instrumentation for commissioning (first turns)
- Injector diagnostics must be treated like storage ring systems! They must be used for beam quality optimizations and possibly for beam-based feedbacks
- Extraction (from booster) and (storage ring) injection elements must be monitored and possibly controlled / adjusted by (beam-based) feedbacks
- During commissioning more and redundant diagnostics systems are required (cost-effectiveness may be paid by increase of tedious commissioning time)
- On-axis injection seems to be a real challenge – not only for diagnostics ☺

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Thank You

… and let's have fun with our DL light source upgrade projects ☺ ☺ ☺