Tests of a new BPM Long Term Drift Stabilization Scheme based on External Crossbar Switching at PETRA III.

G. Kube, F. Schmidt-Föhre, K. Wittenburg, Deutsches Elektronen-Synchrotron DESY, Germany
A. Bardorfer, L. Bogataj, M. Cargnelutti, P. Leban, P. Paglovec, B. Repič, I-Tech, Solkan, Slovenia

Introduction

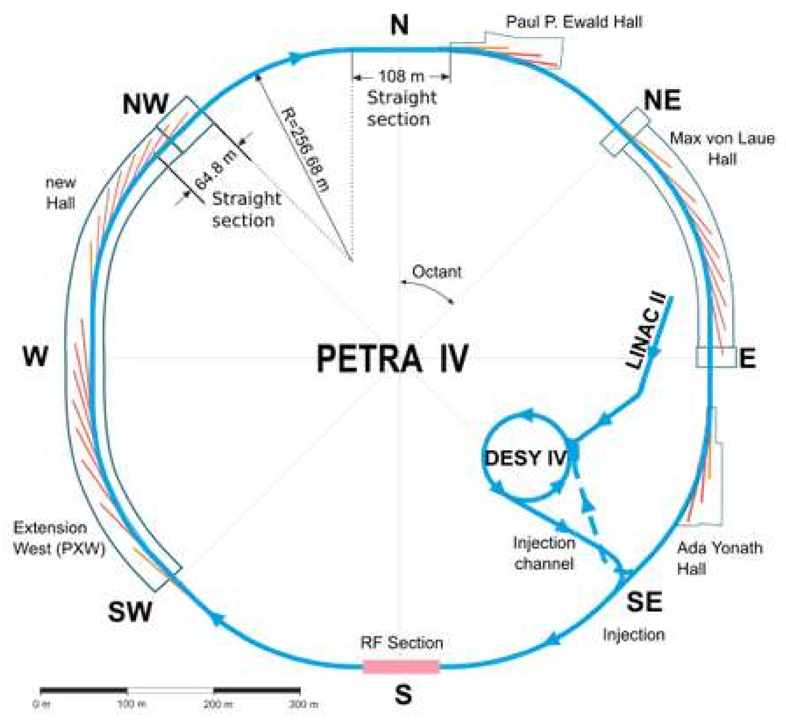
The PETRA IV project at DESY aims to upgrade the present synchrotron radiation source PETRA III into an ultralow-emittance source which will be diffraction limited up to X-rays of about 10 keV [1]. Using an H6BA lattice with a unit cell providing an emittance of 45 pm.rad, the target emittance of about 20 pm.rad will be recovered by a large number of damping wigglers distributed in the short straights of the octants not equipped with user beamlines [2]. This small beam emittance translates directly into much smaller beam sizes of 7 µm at the insertion device source points, thus imposing stringent requirements on the machine stability. In order to measure beam positions and control orbit stability to the requisite level of accuracy, a high resolution BPM system will be installed which consists of ~800 monitors with the readout electronics based on MTCA.4 as technical platform.

[1] C.G. Schroer *et al.*, J. Synchrotron Rad., vol. 25, pp. 1277-1290, 2018.
[2] I. Agapov *et al.* , PETRA IV Report p4-WP201-re-0006, July 2021.

BPM readout specification

- resolution on single bunch / turn (0.5 mA / bunch) — < 10 µm
- resolution on closed orbit (200 mA in 1600 bunches @ 1 kHz BW) — < 100 nm (rms)
- beam current dependence (60 dB range, centered beam) — ± 2 µm
- long term stability (measured over 6 days, temperature span ±1°C within a stabilized rack) — < 1 µm

PETRA IV @ DESY



Design parameter	PETRA III		PETRA IV	
Energy / GeV	6		6	
Circumference / m	2304		2304	
Operation mode	Continuous	Timing	Brightness	Timing
Emittance (horz. / vert.) / pm rad	1300 / 10		< 20 / 4	< 50 / 10

PETRA IV time line

- shut-down PETRA III — beginning 2026
- start PETRA IV operation — beginning 2028

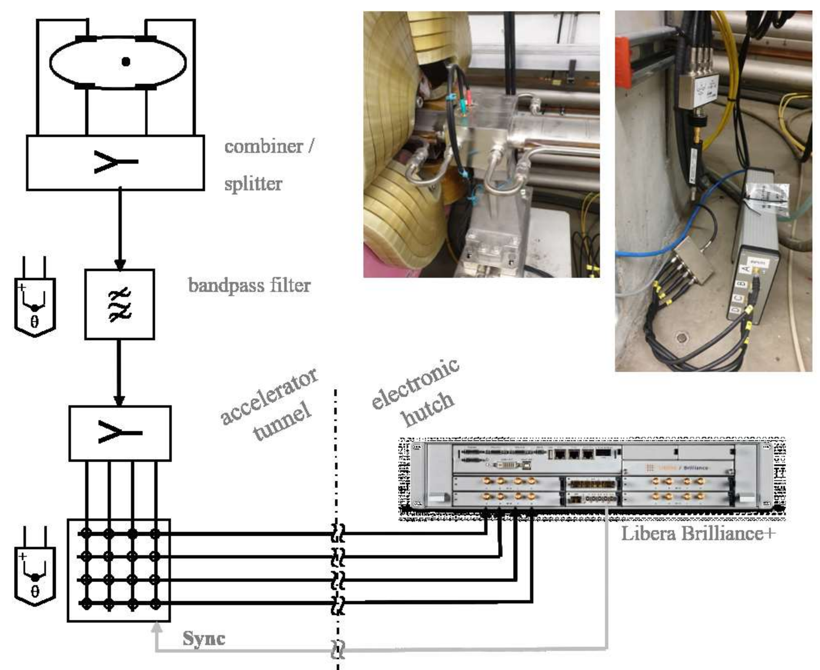
Machine Geometric Implications

In order to fulfill the requested long-term drift requirement for the case of PETRA IV, the specific machine geometry has to be taken into account. Originally, PETRA was built as e^+e^- collider for high-energy physics. Therefore, the machine circumference of 2304 m is much larger compared to light sources, and the machine infrastructure is distributed in the former experimental halls with the result of long cable lengths between monitor and readout electronics. Driven by considerable cost saving, the plan for PETRA IV is to reuse the existing ring tunnel in the areas between the experimental halls. However, the tunnel cross section is too small for housing all required cables, i.e. it will not be possible to interconnect BPM pickups in the accelerator with their corresponding readout electronics in an experimental hall using cable paths inside the accelerator tunnel. As consequence, additional cable access shafts will be required to minimize the arising load inside the tunnel, and it is not guaranteed that cable routing will be in a perfectly stabilized temperature and humidity environment, thus affecting the BPM position readings. Therefore, in order to fulfill the requested long-term drift stability the BPM cable paths have to be stabilized in addition.

Different drift compensation schemes are available: (1) the concept of crossbar switching which is implemented in the Libera modules and stabilizes the analogue RF front-end part of the system. (2) A concept which has gained in popularity in recent years is the pilot tone (PT) compensation method where a sinusoidal PT signal with fixed frequency close to the carrier one is injected in the signal chain. This signal is used as reference for calibration and compensation. If the PT signal is injected close to the BPM pickup before the cable, not only the front-end but also cable drifts can be compensated. **The same effect can be achieved for crossbar switching if the analogue switching part is separated from the read-out electronics and brought as close as possible to the BPM pickup.** In **MOPP036** both methods are discussed in detail and compared with each other. Based on this discussion and tests performed with the PT compensation scheme at PETRA III, it was decided to **follow the idea with external crossbar switching**.

This contribution summarizes first proof-of-principle measurements performed at PETRA III using a modified LB+ with an external switching matrix. These measurements indicate that the concept works well and that the performance of this modified test setup fulfills the specifications f

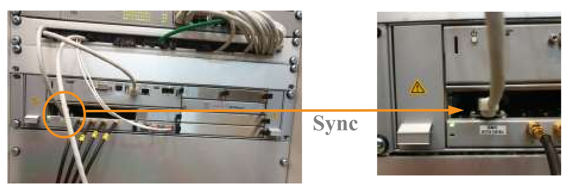
PETRA III Test Setup

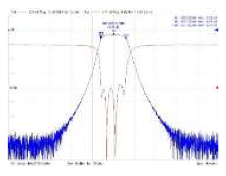


- combiner / splitter: MACOM DS-409-4
- 500 MHz bandpass filter Wainwright Instruments WBK500-15-5SS

electronic hutch

Libera Brilliance+





Long Term Stability Studies

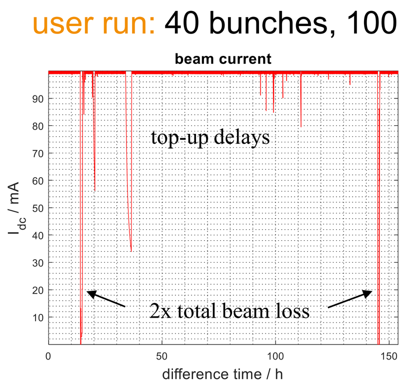
priciple:

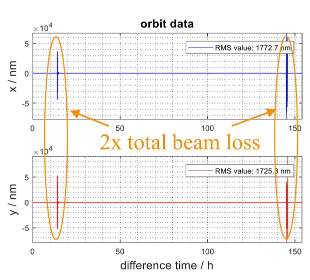
- measurement started end of maintenance day
- stopped one week later (beginning of the next maintenance day)
  → overall measurement time160 h
- take about 50,000 Slow Acqusition (SA) samples

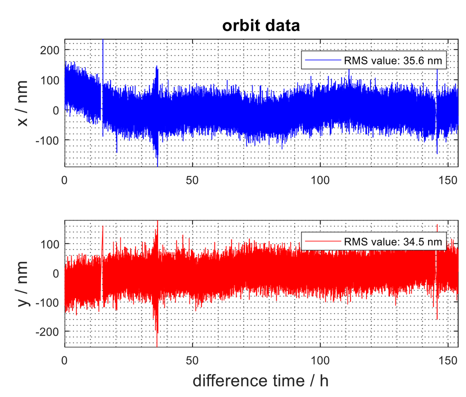
measurement example #1:

- beginning of measurement: switch AGC on for 15s
- afterwards switch AGC off
- crossbar switching & DSC active

user run: 40 bunches, 100 mA







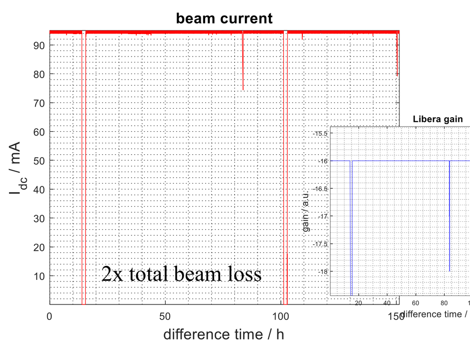
- exclude time of beam loss and refill
  → consider data only for I_{dc} > 25mA

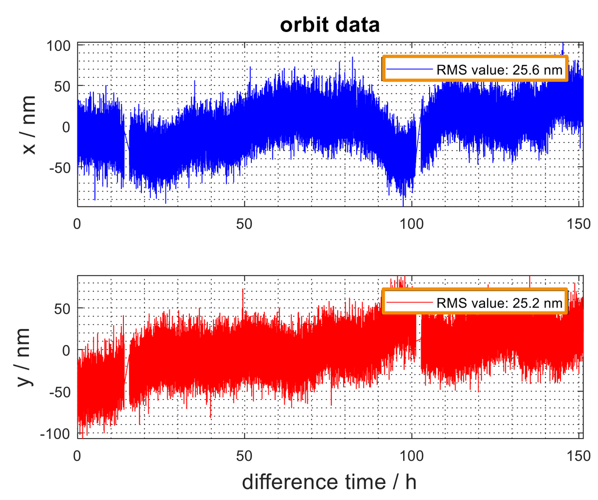
→ rms < 50 nm, p2p < 200 nm

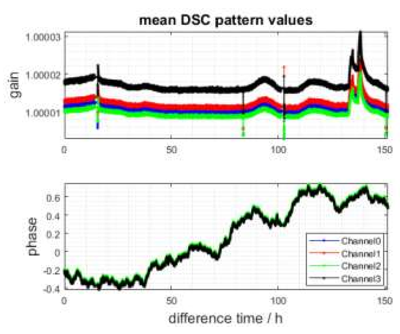
measurement example #2:

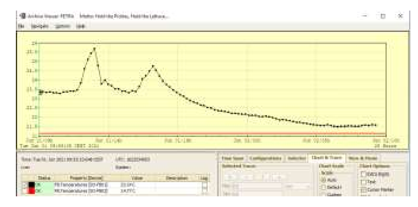
- crossbar switching, DSC & AGC active

user run: 40 bunches, 95 mA

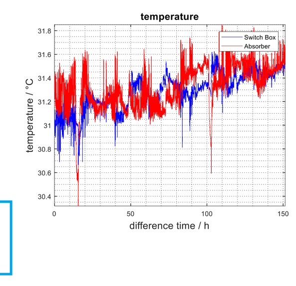








correlation with rack temperature



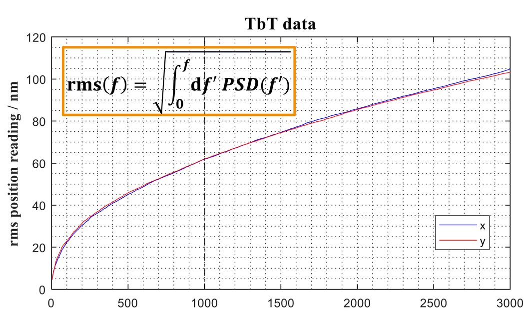
no obvious correlation with tunnel temperature

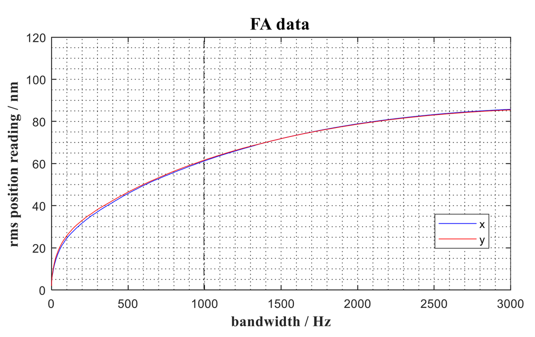
→ long-term stabilization works well

Closed Orbit Resolution

principle:

- 10 files of position readings recorded (each consists of 32768 consecutive samples)
  → Turn-by-Turn (TbT): f_0 = 130.1 kHz
  → Fast Acquisition (FA): f_{FA} = 10 kHz
- transform position measurement in corresponding Power Spectral Density (PSD)
- take mean from 10 data sets
  → averaged PSD
- integrate PSD over frequency
  → resolution as function of bandwidth



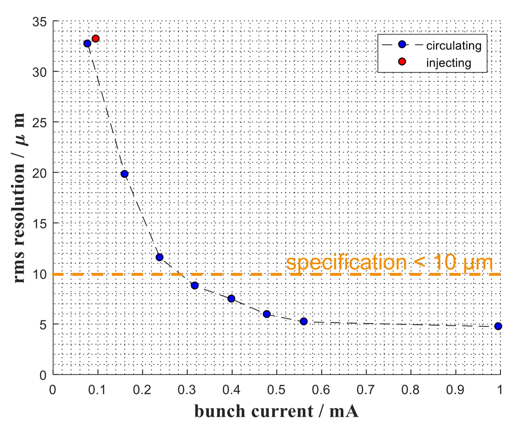


→ < 100 nm @ 1 kHz bandwidth

Single Bunch / (Single) Turn Resolution

principle:

- data collected from Single Pass (SP) data path:
  → minimize resolution disturbing noise contributions via mask in ADC spectrum
  → position information only from that region which contains bunch information
- single turn measurement
  → single bunch injected and dumped immediately after one passage
- bunch current from a single injection not sufficient to test specification at 0.5 mA
  → single bunch measurements with circulating beam at higher bunch currents
  → use of accumulation
- fair if no attenuator switching involved (< 0.35 mA)



→ < 10 µm

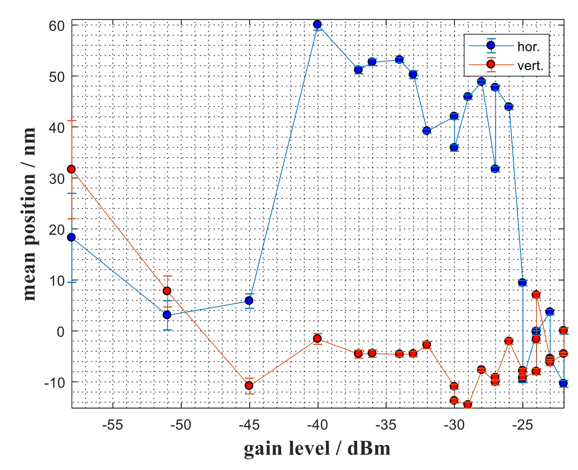
Summary and Outlook

This contribution summarizes first proof-of-principle measurements performed at PETRA III using a modified LB+ with external switching matrix. These measurements indicate that the concept works well, i.e. drifts in the RF front-end and from the interconnecting cables due to environmental changes are compensated to a high level. All long-term measurements performed so far indicate that the achieved readout stability is well below 50 nm (rms) over one week of operation, and independent from the bunch pattern. Furthermore, the overall performance of the readout electronics was investigated, indicating that it is comparable to a standard LB+ but with better long--term stability, thus meeting the specifications for PETRA IV.
In the next step the readout system will be revised to be compliant with the MTCA.4 standard.

Beam Current Dependence

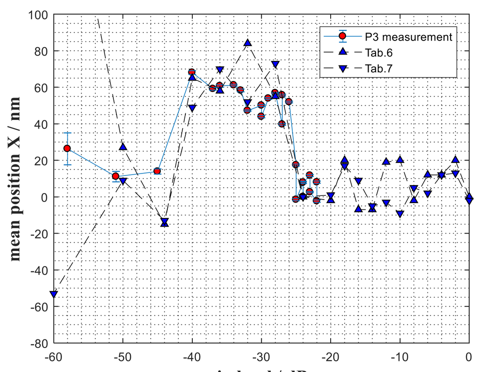
principle:

- PETRA III was filled with 120 mA in 480 bunches
  → beam current reduction via collimator jaws
- position readings recorded both in SA and TbT mode



SA data path

- gain variation covers range of only 40 dB (not 60 dB as specified)
  → protection of external crossbar switching matrix
- comparison with two FAT data sets of same LB+:



FAT / beam data with similar behaviour (hor. data set)

→ < ± 2 µm over 60 dB range