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UPGRADE OF THE BPM LONG TERM DRIFT STABILIZATION SCHEME BASED ON EXTERNAL CROSSBAR SWITCHING AT PETRA III

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Abstract

PETRA IV at DESY will be an upgrade of the present synchrotron radiation source PETRA III into an ultra low–emittance source with beam emittance of about 20 pm rad which imposes stringent requirements on the machine stability. In order to measure beam positions and control orbit stability to the required level of accuracy, a high resolution BPM system will be installed which consists of about 800 monitors with the readout electronics based on MTCA.4. In order to fulfill the requested long–term drift requirement (< 1 µm over 7 days), also the BPM cable paths have to be stabilized because of the PETRA–specific machine geometry. To achieve this, the crossbar switching concept was extended such that the analogue switching part is separated from the read–out electronics and brought as close as possible to the BPM pickup. While first measurements were presented before, meanwhile the system has undergone a major revision, especially the external switching matrix changed from a prototype setup to a system close to the final design. This contribution summarizes the latest measurements from PETRA III, demonstrating the high performance of the external stabilization concept.

INTRODUCTION

The PETRA IV project at DESY (Hamburg, Germany) aims at the construction of a diffraction limited ultra–low emittance light source operating at 6 GeV. The storage ring will be installed in the existing 2.3 km PETRA tunnel, thus it will follow the geometry of the old PETRA collider with 8 octants made of arcs, each hosting nine hybrid six bend achromatic (H6BA) cells which are connected by long straight section as shown in Fig. 1. Given the constraints on the DESY campus, only three octants will host beamlines (named OCTU in Fig. 1). Therefore, the facility will reuse the existing PETRA III experimental halls and will build a new one covering two octants of the ring in the West. The remaining octants (named OCTA) will host damping wigglers (DWs) in order to reduce the H6BA lattice emittance from approx. 43 pm rad down to the target value of 20 pm rad. The PETRA IV design operational parameters are summarized in Table 1, more information about the project and its actual status can be found e.g. in Refs. [1, 2].

The small PETRA beam emittance translates directly into much smaller beam sizes of 7 µm in both planes 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

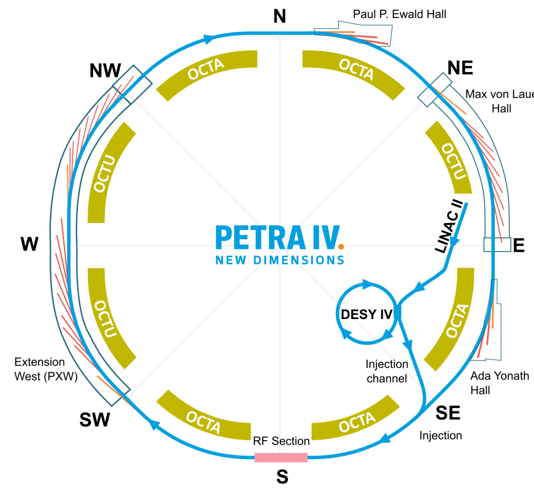

Figure 1: Layout of the PETRA IV facility. Existing experimental halls (Max von Laue, Peter P. Ewald, and Ada Yonath) will be reused, an additional experimental hall in West will be constructed.

Table 1: PETRA IV Main Parameters

Parameter	Value
energy	6 GeV
circumference	2304 m
emittance (with DWs)	20 pm rad
rel. energy spread (with DWs)	0.91×10^{-3}
momentum compaction	3.3×10^{-5}
$\beta_{x,y}$ at IDs	2.2 m, 2.2 m

accuracy, a high resolution BPM system will be installed which consists of 787 individual monitors with the readout electronics based on MTCA.4 as technical platform. In Table 2 the BPM readout specifications are summarized.

As pointed out in Ref. [3], the specific PETRA IV machine geometry has to be taken into account in order to fulfil the requested long–term drift specification. This requires an additional stabilization of the BPM cable paths. Different drift compensation schemes are available and reviewed in Ref. [4]. As outcome of tests performed at PETRA III [3, 5] and of the discussion in Ref. [6] it was decided to use the principle of external crossbar switching where the analogue switching part is separated from the read–out electronics and brought as close as possible to the BPM pickup. Based on this idea DESY and the company I-Tech started a cooperation within the PETRA IV Technical Design Report (TDR) phase. Objectives are development and tests of a MTCA.4

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Table 2: Readout electronics specifications. The single bunch / turn resolution holds for 0.5 mA bunch current, the closed orbit one for 1 kHz bandwidth, the beam current dependency for a 60 dB range with centered beam, and the long term stability should be measured over 6 days and a temperature span of ±1°C within a stabilized rack.

Requirement	Value
single bunch / single turn	< 10 µm
closed orbit resolution	< 100 nm (rms)
beam current dependence	±2 µm
long term stability	< 1 µm

based BPM system. Status of the project and preliminary evaluation of electronic prototypes under laboratory tests are reported in Ref. [7].

This contribution summarizes the latest long–term drift stability measurements performed in summer 2022 at PETRA III. While the MTCA.4 based prototypes are not yet ready to be tested in the accelerator environment, the external switching matrix (Libera XBS FE) is in the final design stage and was tested in combination with a modified Libera Brilliance+ (LB+) [8]. First measurements using different PETRA III operating modes indicate that the test setup performance fulfils the specifications for PETRA IV.

TEST SETUP AT PETRA III

A sketch of the setup in use for the PETRA III studies is shown in Fig. 2. In order to get rid of the beam jitter, a zero–offset emulator is used which consists of a combination of combiner and splitter (MACOM DS-409-4). The output signal is fed to the Libera XBS FE matrix. Outside the accelerator tunnel, the LB+ readout module is mounted in a rack located in an electronic hutch, the length of the interconnecting cables (3/8” Cellflex, LCF38-50JFN) is about 100 m. In order to synchronize the Libera XBS FE with the digital switch matrix inside the LB+, both devices are interconnected via a UTP Cat 7A cable. While the temperature

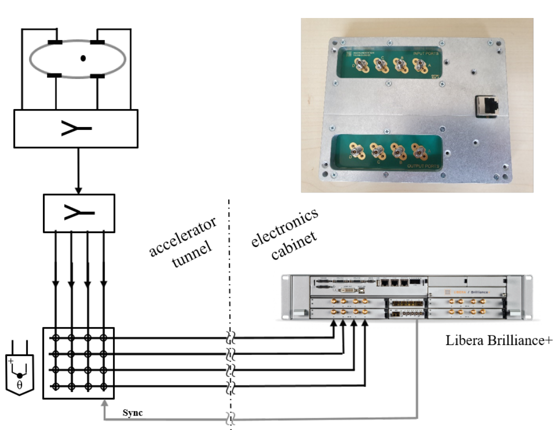

Figure 2: Principle scheme of the test setup. The photo shows the Libera XBS FE switch matrix (physical dimensions: 162.4 mm×128.4 mm×18 mm).

in the electronic hutch is stabilized to a level of ±1°C, the accelerator tunnel at the BPM location is not stabilized and temperature drifts of more than 2°C are possible throughout a week of operation. In order to measure the temperature, the XBS FE is equipped with a temperature sensor.

Compared to the setup described in Ref. [3], the main difference in the present one is the absence of the 500 MHz bandpass filter in the signal chain. Its purpose was to protect the switch matrix input from too high power, but embedding it in the zero offset emulator does not mimic a realistic situation. Instead of using bandpass filters, the Libera XBS FE uses low pass filters in the input of each signal path. Compared to a bandpass, the low pass filter characteristics has a much flatter slope and is less prone to input fluctuations.

LONG TERM STABILITY STUDIES

With the first Libera XBS FE prototype available in summer 2022, a series of measurements was performed. Each measurement lasted at least a few days. Figure 3 shows the temporal evolution of the beam current during about 5 days of user operation. In this time the machine was operated in the so called *continuous mode*, i.e. with a homogeneous filling of 480 bunches in 120 mA. Between 30,000 and 60,000

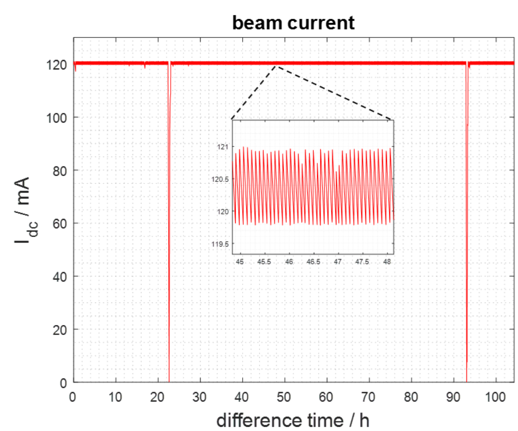

Figure 3: Beam current during user operation in July 2022. In this period PETRA III was operated with I_{dc} = 120 mA in 480 bunches. In this week two total beam losses happened. The insert indicates variations during top-up operation which keeps the current constant to a level of 1‰.

data samples were recorded in Slow Acquisition (SA) mode of the readout electronics with 10 s wait time between consecutive samples. During the measurements, Digital Signal Conditioning (DSC), crossbar switching, and Automatic Gain Control (AGC) were active in the LB+.

In the following, example measurements are presented for both operational modes of PETRA III, the *continuous mode* with a homogeneous filling as described above (16 ns bunch separation), and the *timing mode* with 40 bunches in 100 mA (192 ns bunch separation). Similar modes are also planned for PETRA IV. While the development of modern ADCs is mainly driven by the telecommunication market and the

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ADC performance therefore well suited for sinusoidal input signals (homogeneous filling), the pattern of the timing mode is challenging for a stabilization scheme. The experience from PETRA III tests using a pilot tone compensation scheme indicated at least difficulties in the performance for large bunch separations.

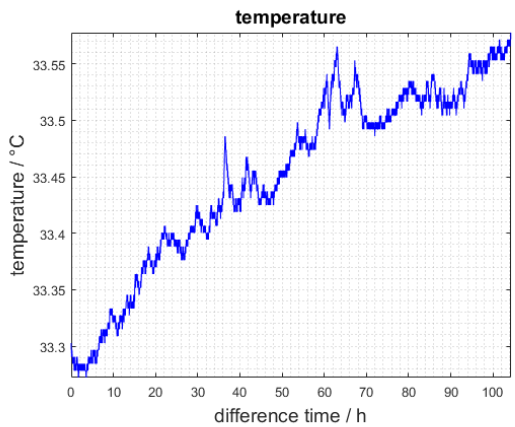

Figure 4: Temperature profile measured at the Libera XBS FE switch matrix.

Continuous Mode: Figure 4 represents the temperature profile as measured with the sensor mounted at the Libera XBS FE switching box. All data shown in this paragraph were taken simultaneously to the current dependency in Fig. 3.

Figure 5 illustrates the temporal evolution of the DSC coefficients gain and phase which both characterize the complex channel gain. As can be seen, a change in the beam current due to a beam loss is immediately visible in the gain, c.f. Fig. 3.

In Fig. 6 the position readout data from the SA data path are plotted. The monitor constant for data representation and beam position analysis amounts to $K_{x,y}$ = 10 mm throughout

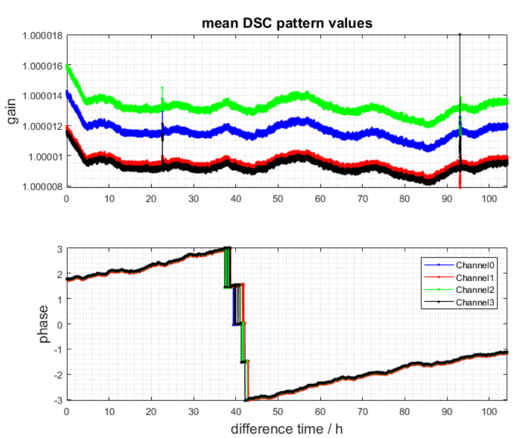

Figure 5: Temporal evolution of the mean DSC coefficients gain (top) and phase (bottom). Both parameters characterize the weighted average of the four data paths and represent a complex channel gain.

this report. In case of beam losses when there is no signal power at the input of the LB+, position readings are useless and a measure of the system noise. In order to exclude this distorting resolution influence, only data for $I_{dc} \geq 115$ mA are considered for the data analysis.

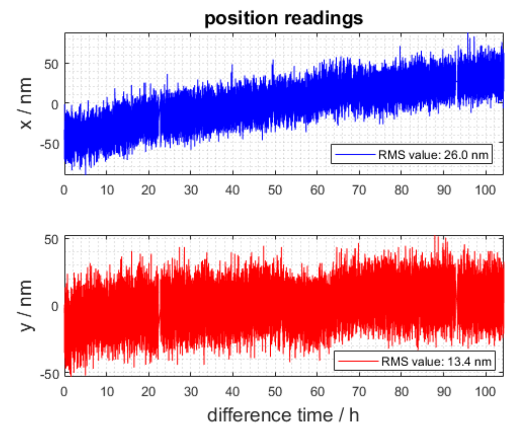

Figure 6: Position readings acquired from the SA data path. The monitor constant is $K_{x,y}$ = 10 mm.

As can be seen from this figure, the long term stability of the position data is very good. The rms values amount to 26.0 nm horizontally and 13.4 nm vertically, the peak–to–peak readings are in the order and below 100 nm which is well below the requested specification of < 1 µm. Comparing Figs. 4 and 6 there might be a small correlation between position readings and temperature profile. However, the effect is very small and the compensation scheme by external crossbar switching works well and compensates temperature together with possible humidity changes on both readout electronics and interconnecting cables.

Timing Mode: In the following a measurement is presented for timing mode operation which lasted about 8 days (192 h). In this time period there were four total beam losses and a few top-up interruptions (minimum beam current amounted to 72 mA, corresponding to a gain variation from −11 dB to −13 dB at the Libera input). The temperature profile as measured at the switching box showed a similar increasing trend than the one in Fig. 4, but with a variation of more than 1.2°C which is much larger compared to the measurements during continuous mode operation. This was most likely caused by the increased outdoor temperatures of about 30°C during the course of this measurement.

Figure 7 illustrates the temporal evolution of the DSC coefficients gain and phase as before. As can be seen from the gain coefficients, day–night variations with a period of about 24 h are clearly visible, especially at the beginning of the measurement. While fluctuations in the gain are larger compared to Fig. 5, the general trend in the phase indicates again a smooth increase (apart from the 90° phase jumps which are caused by numerical effects, but do not hamper the performance).

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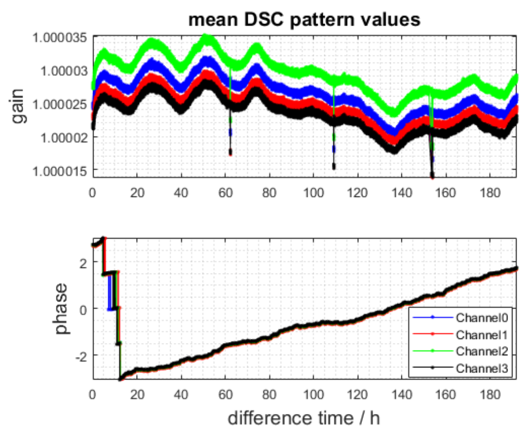

Figure 7: Temporal evolution of the mean DSC coefficients gain (top) and phase (bottom).

Figure 8 shows the corresponding position readout data from the SA data path. Again, in order to exclude distorting resolution influence due to beam losses only data for $I_{dc} \geq 95$ mA are considered for the data analysis. As can be

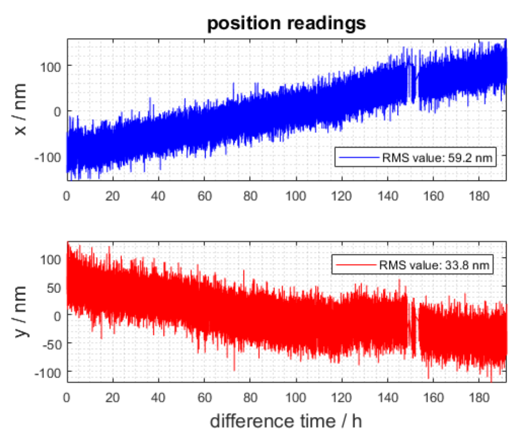

Figure 8: Position readings acquired from the SA data path.

seen, the long term stability of the position data results in rms values of 59.2 nm horizontally and 33.8 nm vertically. These values are about a factor of 2.5 worse compared to the continuous mode with its homogeneous fill pattern, nevertheless they are still well below the requested specification of < 1 µm. However, as pointed out in Ref. [3] the most temperature–drift critical element in the analogue signal chain is the external switch matrix itself, and besides also splitter and cables in front of the Libera XBS FE can contribute. As consequence it is quite likely to assume that not only the fill pattern, but also the environmental conditions during the second measurement with a measured temperature variation of more than 1.2°C at the switch matrix contribute additionally to the increased rms values. Since the tunnel temperature in PETRA IV will be stabilized to about ±1°C, larger drifts are not to be expected.

SUMMARY AND OUTLOOK

This paper summarizes BPM long–term stability studies which were performed at PETRA III using a modified LB+ with external switch matrix Libera XBS FE. These measurements indicate that the concept of external switching compensation 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 the specified 1 µm over one week of operation.

As next step, the MTCA based BPM system described in Ref. [7] which is an evolution of the present system will be installed and tested at PETRA III. Provided that future system tests with beam will demonstrate a comparable performance, the task to develop a prototype BPM system for the PETRA IV TDR phase is completed. Afterwards, the final step will be to transform the prototype into a system for serial production.

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