Overview of the Diagnostics Systems of PETRA III

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Abstract

Since mid-2007, the existing storage ring PETRA at DESY is reconstructed towards a dedicated third generation hard x-ray light source. The reconstruction includes the total rebuilding of one-eights of the storage ring where the FODO lattice of the arcs is replaced by double–bend achromat (DBA) cells. Damping wigglers are installed to reduce the emittance down to the design value of 1 nm rad. In order to fully benefit from this low emittance, beam stability is a crucial issue. This paper presents an overview of the instrumentation and their latest developments.

INTRODUCTION

PETRA III will be a new high-brilliance synchrotron radiation source at DESY [1]. With 6 GeV beam energy and 100 mA stored current the storage ring is on track to deliver the most brilliant storage–ring–based x–rays to users in 2009. The construction activities started in July 2007 when HERA went out of operation after 15 years of delivering high energy physics data. The 2.3 km long accelerator is completely redesigned, including the total rebuilding of one–eights of the storage ring where 14 undulators (incl. 5 canted) in 9 straight sections were installed. A new 300 m long experimental hall covering this octant with 14 independent user beamlines and one for emittance diagnostics was recently build. The remaining 7/8 of the storage ring was refurbished, including a new design of the vacuum system together with the beam position monitors (BPMs). Two damping wiggler sections (total length 80 m) were installed to to damp the emittance to the design value of 1 nm rad. At the nominal current of 100 mA the emitted wiggler power amouts to 410 kW. In the following the beam diagnostics and instrumentation will be described.

BEAM CURRENT MONITORS

Wide-band in–flange fast current transformers (FCTs) with a bandwidth of 1.75 GHz (*Bergoz*) will measure the individual charge of each stored bunch. From this measurement the required individual bunch charge for top–up injection is deduced. A resolution of $< 1\ \mu$A/bunch with analog BW = 500 MHz is intended (to meet 2 ns bunch spacing at a later stage). Its readout is performed by a scope type Wave–Runner 104Xi (LeCroy) with a sampling rate of 10 GS, a bandwidth of 1 GHz and 8 bit resolution. An average of about 50 turns of each bunch is displayed in the control room and sent via Ethernet connection to the control system. Two customized elliptical FCTs (BW = 800 MHz) are located in the injection area to determine the injection efficiency.

For a high resolution measurement of the stored DC current three parametric current transformers (*Bergoz*) will be used which are reused from PETRA II and HERAe and upgraded by the company. Experiences from HERA with this type of monitor showed a resolution of $\sigma \ll 0.1\%$ (3 μA at 61.7 mA) [1] which is sufficient for the top-up operation of PETRA III. The readout is performed by a high precision DVM (Type HP 3458A with 16 - 24 bit resolution depending on sampling rate), connected to the Bergoz back–end electronics. The DVM takes the average over a predefined number of turns.

BEAM POSITION MONITORS

The accelerator is equipped with 227 beam position monitors (BPMs) of seven different pickup types, their properties are summarized in Ref.[2]. The BPM system has to serve for i) machine commissioning and development and for ii) orbit feedback and observation. In the first case single turn and single pass capability is required to acquire beam positions for the non–stored first turn and each of consecutive turns with relaxed resolution requirements of 50. . .100 μm. In the second case (standard user operation) the beam orbit of the stored beam has to be kept constant with respect to the reference orbit. All BPMs have to be squeezed to their maximum performance in terms of resolution and reproducibility. Therefore the bandwidth of the BPM–readout will be reduced to 300 Hz and averaged position measurements of many turns will be acquired.

In addition the BPM system has to provide position data with a frequency of about 130 kHz (turn by turn) as input for the fast orbit feedback system. Even at that bandwidth the resolution of a BPM must not exceed 50 μm.

All tasks are foreseen to be fulfilled with the new LIBERA *Brilliance* BPM electronics from *Instrumentation Technologies*. In a number of test measurements it was demonstrated that the required specifications [3] are covered already with the LIBERA *Electron* version, however three parameters were discovered to be critical: i) the LIBERA temperature drift of 0.2 μm/°C which allows to operate the electronics only in air–conditioned surroundings, ii) the maximum input voltage of the channels [4] which requires the use of additional 10 dB attenuators, and iii) the bunch

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pattern dependency of the position readout which should be eliminated with the LIBERA *Brilliance*. If there will be still a considerable dependency for extreme bunch patterns it is planned to generate different reference orbits for certain fillings.
Position and movement of each pickup at critical locations will be measured with respect to the ground floor or girder. All pickups in the new octant are attached to a "High Frequency Movement Monitor" which determines pickup movements with a resolution of $\ll 1$ μm, based on the measurement of the distance between 4 terminated (50 Ω) striplines (two per plane) and a stiff solid wire of 2 mm diameter. The wire is mounted on a fork which is firmly connected to the ground or girder by a massive support. It is part of a matched 145 MHz λ/4-resonator and the striplines pick this RF signal up . The 4 signals are processed like usual BPM signals to determine the position of the wire inside the pickup (monitor constant k = 3.0). The bandwidth (BW) of the system is about 1 Hz, sufficient to observe long term drifts.

X-ray BPM: An X-ray BPM based on the ionization of residual gas was developed and tested. It uses the ions created by the X-ray beam in a small pressure bump of about 10^{-6} mbar. The ions are accelerated by a parallel electrical field towards a Micro Cannel Plate and an attached phosphor screen. This monitor type has the advantage of imaging the whole body of the beam so that the center is well defined. Tests with a prototype at the ESRF showed a resolution of better than 5 μm [5].

EMITTANCE

X–ray diagnostics beamline: The diagnostics beamline is located at the end of the new octant. Synchrotron radiation (SR) from a bending magnet central field with critical photon energy of 20.907 keV is used to image the beam spot onto a high resolution CCD camera system. Imaging will be performed with two interchangeable x–ray optics: A compound refractive lens (CRL) system (31 beryllium lenses, ~ 2 μm resolution) and a pinhole camera system (0.5 mm thick tungsten blade with circular hole of 20 m, ~ 20 μm resolution) for lower resolution standard operation. A Si crystal (311 in Laue geometry) located 8.78 m behind the x–ray optics is used to select 20 keV photons. The detector system (Hamamatsu AA50 beam monitor) is installed outside of the vacuum system. It consists of a 10 mm thick LSO scintillator screen together with a microscope optics and a progressive scan interline chip CCD camera (Hamamatsu Orca C4742-80-12AG).

Optical beamline: The optical diagnostics beamline for bunch length diagnostics uses synchrotron radiation from a standard dipole magnet in the old octants (critical photon energy 2.499 keV). A water cooled Cu mirror extracts the optical part of synchrotron radiation from the dipole, and an optical relay system guides the light to an experimental hut outside the tunnel. In the beginning it is foreseen to perform measurements of the bunch length with fast optical elements like a streak camera or Avalanche photo diodes. To be prepared for measurements of the beam size in the optical spectral region as well, all optical elements are designed and proven to be as precise as possible (peak to valley wavefront aberration of λ/20 at 632 nm).

Laser wire scanner: A pulsed Nd:YAG laser (532 nm), capable of delivering 7.5 MW light pulses at 20 Hz, is installed in a hut outside the tunnel. A light polarization based, fast splitting technique will be applied. A Pockels cell at the laser hut allows pulse by pulse splitting of the laser beam to enable horizontal and vertical scans. Left/right helicity pulses made by the Pockels cell reach the tunnel and are converted into horizontal/vertical polarisations by a quarter wave plate followed by a Glan-laser prism-splitter. This prism guides laser pulses with vertical/horizontal polarization to different scanning arms (one for each plane). Each scanning arm will contain a bending transverse Pockels cell for scanning and a lens to focus the beam down to a laser spot size of about 5 μm. A vacuum chamber with an outlet in the next dipole allows a safe transport of the scattered photons with few hundred MeV energies into the detector. The photon detector is a tungsten-scintillator sandwich with 2 segments to allow vertical position detection. The whole setup will allow a complete 2D transverse scan in about 30 s within a few percent accuracy [6].

ORBIT STABILIZATION, FEEDBACK AND TUNE

The stabilization system has to suppress slow motions of the particle beam within time constants from several days to 300 Hz. The requirement is 10% of the beam sizes, which is about 4 μm for the horizontal and 0.5 μm for the vertical plane at the location of the insertion devices.

Orbit correction: Slow orbit corrections will be performed by the control system based on the readout of the 220 BPMs. The LIBERA electronics are connected via Ethernet to the control system while its readout frequency is about 1 s for each box. Singular value decomposition (SVD) is applied for simultaneous optimization of the closed orbit and the dispersion.
A fast orbit feedback will reduce orbit distortions by about 20 dB at 50 Hz with a slope of -20 dB/decade. Its low frequency components does not overlap the high frequency range of the slow orbit feedback. Both systems work independently, however at a later stage a synchronization is foreseen. Turn by turn position informations from all BPMs are joined onto 24 signal combiners. Each combiner generates a fast data stream into optical fibre lines (up to 200 MB/s synchronous data flow) which are connected with a main processing unit in star topology. A main processing unit manages data collection, processing

and distribution. Signal processing will be performed using SVD and PID algorithms in FPGA technology. The output data stream is distributed via fibre links to 82 digital power amplifiers (DPA), each connected to a fast air coil corrector. The frequency range covers from DC to 1 kHz. The whole setup is a complete end–to–end digital design with 16 bit resolution.

Multibunch feedback systems: The design current in PETRA III can only be achieved with powerful bunch by bunch feedback systems. The required minimum bandwidth is 62.5 MHz (8 ns bunch distance). Transverse feedback: The signals of two dedicated stripline beam position monitors are connected to an RF front–end (in-house development) followed by a FPGA based signal processing board. It drives 4 feedback power amplifiers per plane (Bonn Elektronik, Type BSA 0125-250) with a frequency range of 9 kHz to 250 MHz and an output power of 250 W each. The amplifiers drive 4 stripline kickers (2 per plane) which are designed and built in–house. Longitudinal feedback: 4 BPM button signals are combined, resulting in a position–independent intensity signal. The longitudinal signal chain consists of an RF front–end and a digital signal processing board as for the transverse system. The kicker devices consist of 8 modified DAΦNE cavities [7]. They are well tuned and damped to achieve the required bandwidth of 62.5 MHz. With a center frequency of 1375 MHz double sideband modulation will be used. A later modification for 250 MHz bandwidth is possible by changing the tuning and damping of the cavities together with single sideband modulation at the same center frequency.

Tune: The tune measurement is part of the transverse multibunch feedback system. It contains a digital signal generator to feed different kind of signals bunch–synchronized to the kickers. Single and multi bunch excitations can be performed. In the single bunch mode the number of bunches can be selected while in multi bunch mode the frequency of each mode can be adjusted. Different excitation schemes exist: 1) sinusoidal CW, 2) bursts with adjustable rate and length, and 3) bandwidth–limited "white" noise. Since the feedback systems will damp away any kind of excitation classical tune measurements can be performed only without feedback. However, a different method for tune measurements with feedback will be tested: an adjustable broadband noise will be added to the RF front–end output and therefore to the kickers. In the frequency response this can be observed as constant offset. At the tune resonance frequency a notch will appear due to the 180° feedback phase shift. These notches can be analyzed very precisely, even with running feedbacks and with a minimum of excitation. A detailed description of this system is in preparation.

MACHINE PROTECTION SYSTEM

The accelerator will be equipped with a ring–wide machine protection system (MPS) which will dump the beam in critical situations. One or more MPS crates are located in each of the 8 "old" PETRA halls. Each crate houses an interface to a field bus (SEDAC), a MPS-Controller (MPSC) and 1 to 10 Alarm-Input-Modules which can sample up to 16 alarm inputs. Alarms might come from the BPMs (LIBERA interlock output), the temperature system (>1500 PT100 sensors), vacuum pumps and valves, the RF system, power supplies, etc. The alarm inputs can be enabled and disabled by software or automatically by predefined conditions. Especially the beam current is directly connected to a special module to make the MPS independent from any network connection. The live value of the current monitor (PCT) is always checked by test–pulses through a special winding in the monitor.
All crates are connected with an optical fibre dual loop (redundancy) via the MPSC. This loop synchronizes all crates to the same beam turn. In case of an alarm the corresponding MPSC activates the dump and the post mortem trigger which is distributed to all other crates by the optical fibre loop. The dump trigger is connected to the RF system which will stop to deliver power to the beam and the beam will be lost within ≈4 ms. The delay of the dump trigger with respect to the alarm does not exceed 100 μs. Two massive pieces of metal will also be driven into the beam pipe to ensure no survival of the beam (delay $\geq$ 100 ms). A faster dump kicker (1 turn) triggered by the MPS is foreseen at a later stage. The MPS will keep the information of the channel which delivered the first alarm to simplify the search for responsible candidates. A post mortem trigger will be available at each crate to enable post mortem analysis of connected subsystems.

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