COMMISSIONING RESULTS OF BEAM DIAGNOSTICS FOR THE PETRA III LIGHT SOURCE

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Abstract

PETRA III is a new hard x-ray synchrotron radiation source which will be operated at 6 GeV with an extremely low horizontal emittance of 1 nmrad. This new facility is the result of a conversion of the existing storage ring PETRA II into a light source. The conversion comprises the complete rebuilding of one eighth of the 2304 m long storage ring, which will then house 14 undulator beam lines, the optical and experimental hutches, and the modernization and refurbishment of the remaining seven eighths. In addition two 100 m long damping wiggler sections have been installed which are required to achieve the small design emittance. Construction, installation and technical commissioning have been finished middle of March and then the commissioning with beam started. In this paper we present the results that have been achieved during commissioning with special emphasis on the role of diagnostic systems.

INTRODUCTION

At DESY the former storage ring PETRA II with a circumference of 2304 m has been converted into a dedicated light source PETRA III [1], [2]. This new source is a third generation, hard x-ray facility similar to APS, ESRF and SPRING8 and serves as a supplement to the X-FEL which will be build at DESY. The basic parameters are given in table 1.

Table 1: PETRA III parameters

Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2304	
Total current / mA	100	
Number of bunches	960	40
Lifetime / h	24	2
Emittance (horz. / vert.) /nm	1 / 0.01	
Number of insertion devices	14	

The emphasis of the conversion was on achieving a very small horizontal emittance and to solve the stability problems that are usually connected with high brightness beams.

The number of insertion devices is rather modest for a machine of this size but this due to the fact that the conversion should be cost effective.

PETRA II consisted of eight almost identical parts which are usually called octants. One of the octants has been completely removed and replaced by a new experimental hall of almost 300 m length and 30 m width (see Fig. 1).

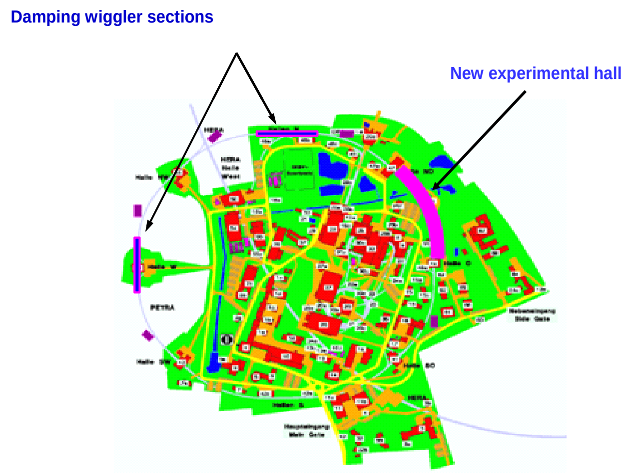

Figure 1: Ground Plan of the DESY site with the PETRA ring. The new experimental hall (purple) is situated between the PETRA halls North-East and East and the damping wiggler sections are in the North and West.

This new hall houses the experimental huts and supplies 9 straight sections in a DBA lattice to install insertion devices. The concept of canted undulators has been applied so that PETRA can be equipped with 14 undulators. Presently 3 two meter long undulators have been installed.

The geometry and the lattice of the remaining seven so called old octants have been kept. The existing hardware was reused if possible but refurbished and modernized to fulfil the high demands on reliability of a light source.

The emittance of the combination of the seven old octants and the new octant is roughly 4 nm rad, well above the design goal. Damping wigglers have been installed to enhance the radiation damping of the machine and thereby reduce the emittance to the required value [3]. These damping wigglers [4], [5] have been accommodated in the long straight sections in the North and West.

The conversion was finished middle of March and then the commissioning of PETRA III started.

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Commissioning of an accelerator requires lots of different diagnostics. The instrumentation for PETRA III has been described in detailed elsewhere [6], [7]. In the following the commissioning procedure and the role of diagnostics will be presented.

COMMISSIONING OF THE TRANSFER LINE

The transfer line is a 190 m long transport channel between DESY and PETRA. It consists basically of a very long straight part of about 160 m length, including a drift space of almost 100m and a short arc in front of PETRA that ends at the injection septum.

The essential elements for commissioning were the 10 screen monitors and two current monitors close to the beginning and the end of the transfer line. Screen monitors have been chosen in addition to eight normal BPMs because they have the obvious advantage of measuring both the position and the profile. With the help of the screen monitors it was easy to get the beam through the channel within about 3 hours. Additional time was devoted to improve the transfer efficiency and to roughly check the optics.

A computer model of the transfer line has been set up which allows to calculate different beam parameters and in particular the beam profile at the different screen monitors. By comparing the theoretical profiles with the measured it could be verified that the profiles agree within 10 % which is sufficient for the time being.

The above mentioned straight section contains a long drift space where three screen monitors have been installed which will allow the determination of the DESY beam emittances and the optics at the end of the drift space. These parameters will then serve as input for matching the optics of the transfer line to the required values at the end.

The eight BPMs of the transfer line, three at the beginning and five at the end, have been commissioned as well [8]. The BPMs worked well right from the beginning and the readings agree with the measured positions of the screen monitors. With the help of these BPMs the trajectory in the transfer line will be checked in the future since efficient injection into PETRA requires stable conditions in particular the stability on vertical position and angle is rather critical. A feedback to control these parameters can be installed.

In addition two scrapes have been installed in the transfer line. They can be used to tailor the beam from the synchrotron if necessary.

COMMISSIONING OF THE STORAGE RING

The first commissioning phase of the machine was done without damping wigglers simply to reduce complexity. The primary objectives were to store and accumulate beam and to set up part of the bunch by bunch feedback system to condition the vacuum system with as high current as possible. In addition first tests of different diagnostic elements should be carried out which are for example necessary for the future operation with wigglers and undulators.

First Turn and Stored Beam – BPM System

The first goal was to get the beam around and to store beam.

To set up the septum amplitude and timing two screen monitors have been installed one just behind the septum and the other 90° in horizontal betatron phase behind the septum. Apart from these two screens no more have been installed to avoid possible (vacuum) problems in the long run. The success of the first goal depended completely on the reliable operation of the BPM system in particular on the turn by turn capability.

Because of the importance of the BPM system the specifications have carefully worked out [9]. It has been decided to purchase the latest version of the BPM electronics from I-Tech (Libera brilliance) and it has been checked, if possible, at other storage rings that the electronics fulfils the requirements [10]. The commissioning of the BPM system is described in a companion paper to this conference [11].

The survival of the beam could be easily checked with the sum signals of the BPMs which serve in this case as a huge number of intensity monitors. If one got stuck somewhere the position information easily helped to correct the trajectory so that the beam was transported further. The first turn was completed on Easter Sunday after two quadrupoles with the wrong polarity had been identified and the optics was locally changed in order to circumvent a problem with another quadrupole. The first and even a tiny bit of the second turn could be also seen on an AC current monitor.

In order to store the beam the trajectory in the new octant, where all the small gap chambers are located, had to be corrected empirically so that the beam survived for up to a few hundred turns. The next step was to turn on the rf-system, to set the rf-phase correctly and then about 10% of the initially injected particles were stored.

Preparation for Accumulation

Next it was aimed to get the optics of the machine as close as possible to the theoretical values. The integer part of the tune was determined by analysing difference orbits in the vertical and horizontal plane. To determine the non-integer part of the tune and other important machine parameters such as chromaticities a reliable tune measurement is absolutely necessary. The non-integer part of the tune was first measured with a special monitor being just dedicated to run in the turn by turn mode. But in most cases the tune was measured by exciting the beam with white noise by the kicker magnets of the bunch by bunch feedback and measuring the response with the transverse feedback detector.

In this way the tunes and chromaticities could be set close to the design values and the orbits could be corrected within 2mm horizontally and 1.5 mm vertically.

Orbit correction was limited by the fact that the position of the BPMs was just known within ± 1.5 mm.

After these corrections the on-axis injection efficiency was close to 100%.

In order to improve the aperture of the storage ring the machine was scanned with bumps at those locations where aperture limitations are likely to be expected i.e. close to the small gap undulator chambers in the new octant and the synchrotron light absorbers in the damping wiggler sections.

After having empirically centred the beam at the critical positions accumulation was set up. First up to 1 mA was piled up in a single bunch. The current was deliberately limited to this value because for higher single bunch currents the peak current could be so high that the corresponding peak voltage could damage the front-end of the monitor electronics [12]. In addition to the current limitation attenuators have been installed to protect the front-end of the monitor electronics. This problem will be relaxed in the future because the bunches will be longer when operating with wigglers so that even the attenuators can be removed. Operation with wigglers will allow reaching the design single bunch current of 2.5 mA.

As the next step the kicker timings were set up correctly so that multi-bunch fillings are possible. Presently 40 bunches are evenly filled and at that time the current was limited to about 5 mA due to transverse coupled bunch instabilities.

Increasing the Current – Bunch by Bunch Feedback

For efficient conditioning of the vacuum system currents of at least 40 mA should be stored. It was expected that the current in PETRA III would be limited by coupled bunch instabilities [13]. That's why the old PETRA II transverse bunch by bunch feedback system [14] has been reinstalled and a new transverse and longitudinal system has been installed. The new system has a bandwidth of 62.5 MHz allowing to evenly fill up to 960 bunches (distance between bunches 8ns) whereas the old system has just a bandwidth of 5 MHz so that even fillings of up to 80 bunches are possible.

The old system was put very quickly into operation, since it is known very well, in order to get rid of transverse instabilities. A current of up to 20 mA was achieved and now the current was limited by longitudinal instabilities. During the next commissioning phase the longitudinal system will be activated to overcome this limitation.

In addition to the deliberately set limit for the single bunches a limit on the total current was also applied. Because of HOM heating there exists the danger to damage the BPMs. Limiting the HOM power due to transient heating to 5 W the resulting current limit is [15]

$$I_{tot} \leq 3.6mA \cdot \sqrt{N}$$

where N is the number of bunches. For an even filling of 40 bunches the limit for the total current is approximately 23 mA. In case of operation with wigglers the situation is relaxed because of the longer bunches. For the next commissioning phase temperature measurements at selected monitors have been prepared so that the above mentioned limit can be checked.

Above the importance of tune measurements was already mentioned. Tune measurement via external excitation under feedback operation is obviously difficult because of the strong damping. Already in the past an alternative way was found to measure the tune with feedback and this method was applied at HERA and is applied at DORIS [16], [17]. Looking at the signal just behind the analogue detector of the feedback system (DS) it can be seen that the noise level is reduced close to the tunes (see fig.2 and 3).

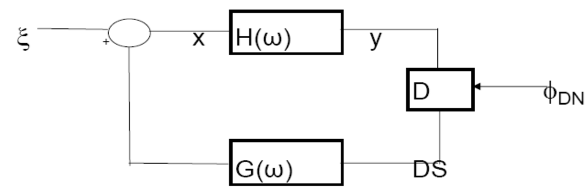

Figure 2: Schematic layout of a feedback system: Beam dynamics is described by H(ω) and the feedback effect by G(ω). The feedback detector is denoted by D and the noise associated with the detector by Φ_{DN}. The signal behind the detector is denoted by DS. External disturbances of the beam are indicated by ξ.

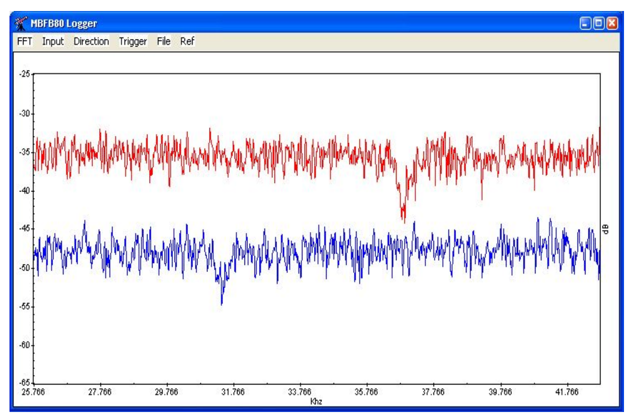

Figure 3: Signal measured behind the detector (DS). The dips in the noise spectrum at the tunes are clearly visible.

This result can be understood if one assumes for simplicity that the beam dynamics is given by a harmonic oscillator and the feedback effect is a differentiator leading to damping. The detector signal is then given by

$$H(\omega) = \frac{1}{\omega_0^2 - \omega^2}; \quad G(\omega) = i\omega\Gamma;$$

$$DS(\omega) = \frac{1}{\omega_0^2 - \omega^2 + i\omega\Gamma}\xi + \frac{\omega_0^2 - \omega^2}{\omega_0^2 - \omega^2 + i\omega\Gamma}\phi_{DN}$$

At the tunes ω= ω_0 the detector signal is reduced if the damping of the feedback Γ is non zero. Observation of these signals shows (i) if the feedback is working and (ii) offers the possibility to measure the tunes.

Preliminary Parameter Studies of PETRA III

With the help of the orbit as well as the tune measurement several properties of PETRA III can be determined. During the first commissioning phase several of these measurements have been performed as preparations for the next phase and to test procedures.

The circumference of the machine has been determined. For each of the four sextupole families, the dependence of the tune on variation of the rf-frequency was measured for three different current settings of the sextupoles. The results were three different lines "rf-frequency vs. tune" for each sextupole family. These lines intersect for zero momentum error and the corresponding frequency is the centre frequency. This frequency determines also the circumference of the machine or precisely the orbit that passes on average through the sextupoles. Fig.4 shows an example of such a measurement.

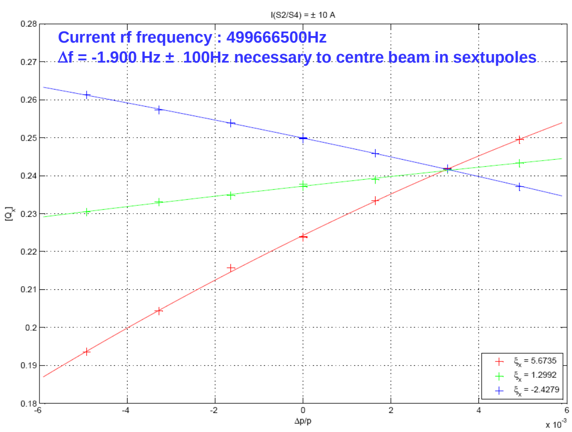

Figure 4: Tune vs. momentum error (rf-frequency) for one sextupole family. The lines intersect for zero momentum error and the corresponding frequency defines the circumference of the machine.

As a by-product of the above measurement the dispersion is determined. For the time being both the horizontal and the vertical dispersion are considerably distorted. Actually this is not really a surprise but simply reflects the fact that the orbit is not well enough corrected. The measured dispersion distortions of up to 10 cm are in accordance with the orbit distortion of 2 mm horizontally and 1.2 mm vertically.

During the first commissioning phase it did not make sense to correct the orbit to a level better then 1 or 2 mm since the position of the monitors was only known within ± 1mm. To make progress beam based alignment (BBA) is mandatory and this is foreseen for the next phase. The BBA procedure has already been tested with a single power quadrupole and found to be working.

Another important procedure is the determination of the orbit response matrix (ORM) and the latter analysis for example with loco. This procedure has been tested with a small number of horizontal and vertical correctors and analyzed. No principle optic error has been identified but there is a small deviation from theory. This will be analyzed in more detail during the next phase.

TESTS OF DIFFERENT INSTRUMENTS

Current Monitors

A fast current monitor which is able to measure the current of individual bunches has been installed and tested. In combination with a marker system it allows to identify bunches and their individual current. This information is important for top-up operation. Basically top-up operation has been prepared and can be applied during this year.

A DC monitor to measure precisely the current and lifetime of the beam has also been successfully tested.

Temperature Sensors

Temperature sensors are installed at several places in particular to survey the temperature of the absorbers in the new octant and in the damping wiggler sections. The temperatures of these elements are available in the control system. If the temperature of some of these sensors exceed a predefined threshold an alarm is sent to the machine protection system to prevent the destruction of the controlled vacuum component. For details on the machine protection system see the contribution to this conference [18].

Movement Detection of the BPMs

The stability of the BPM locations, especially those close to the undulators, are critical because the measured beam position enters into the orbit feedback. Any kind of misreading will result in mis-steering of the beam. The location of the BPMs in the new octant is therefore detected with a special wire system. Basically the position of a wire firmly fixed to the BPM is measured against 4 electrodes which are connected either to the ground or the girder.

Some of the monitors have been successfully tested. The position information of the BPMs will enter the orbit feedback system.

EMITTANCE MEASUREMENT

Two diagnostic beamlines and a laser wire-scanner were built up for longitudinal and transverse emittance measurements. They will be commissioned in the next phase. The following subsections give a short overview, details can be found in Ref. [6].

X-Ray Diagnostic Beamline

A diagnostic beamline for x-ray bending magnet synchrotron radiation was installed at the end of the new octant to image the beam spot onto a high resolution CCD camera system. Imaging will be performed with two interchangeable x-ray optics: (i) a high resolution compound refractive lens (CRL) system (31 beryllium lenses, ≈ 2 μm resolution), and (ii) a pinhole camera system (0.5 mm thick tungsten blade with circular hole of 20 μm, ≈ 20 μm resolution) for lower resolution in standard operation. A Si monochromator crystal (311 reflection in Laue geometry) will be used to reflect 20 keV photons onto the detector system (Hamamatsu AA50 beam monitor) which is installed outside of the vacuum system.

Optical Beam Line

The optical beamline for bunch length diagnostics uses visible synchrotron radiation from a standard dipole magnet in the old octants. A water cooled Cu mirror extracts the optical part of synchrotron radiation from the dipole, and an optical relay system guides the light about 25 m to a streak camera system (Hamamatsu C5680 Streak Camera) which is housed in an experimental hut outside the tunnel. To be prepared for measurements of the transverse 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 laser-wire scanner is providing horizontal and vertical profile measurements within tens of seconds with a sub-percent accuracy. For such a resolution the laser-wire diameter has to be below 10μm which is verified by in-situ calibrations (see Fig. 5). The laser light will be transported from the laser hut 6 m above the PETRA tunnel to a vertical and horizontal optical table positioned around the vacuum chamber. Both tables are equipped with scanning, focusing and diagnostics optics [6]. All installations are finished and the commissioning will follow as soon as stable beam conditions will be achieved.

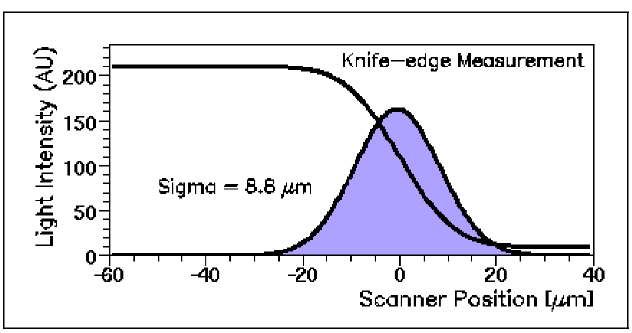

Figure 5: A sample of laser spot size measurement at focus. A knife-edge scan is differentiated to obtain a beam profile.

SUMMARY

The first commissioning phase of PETRA III went smoothly and very fast. No major problem was encountered. Detailed investigation of the machine will be part of the next phase. The success of the first phase is certainly due to sufficient diagnostics that worked well right from the beginning. At this point also the support and commitment of those who took part in the commissioning is greatly acknowledged.

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