PETRA III: A NEW HIGH BRILLIANCE SYNCHROTRON RADIATION SOURCE AT DESY

Klaus Balewski, Werner Brefeld, Winfried Decking, Yongjun Li, Gajendra Kumar Sahoo and Rainer Wanzenberg
Deutsches Elektronen Synchrotron (DESY), Notkestrasse 85, 22607 - Hamburg, Germany

Abstract

DESY has decided to rebuild its 2304 m long accelerator PETRA II into a dedicated light source called PETRA III. The reconstruction is planned to start mid 2007. The new light source will operate at an energy of 6 GeV, a current of 100 mA, a horizontal emittance of 1 nmrad and an emittance coupling of 1%. In the first phase thirteen insertion devices are foreseen. In this paper the principle layout of the machine will be presented. The structure of the new machine combines properties of conventional storage rings and light sources and is therefore quite unconventional. One of the major challenges of the project is to achieve the small emittances. The basic idea is to use so called damping wigglers with a total length of 80 m to reduce the horizontal emittance to the desired level. To obtain and maintain the small emittances imposes tight tolerances on spurious dispersion and orbit quality and stability. These limits will be given and discussed.

OVERVIEW

In order to meet the future demands for synchrotron radiation at DESY it has been decided to convert the existing storage ring PETRA II into a dedicated light source [1]. Since PETRA II has a comparatively large circumference of 2304 m the new light source PETRA III should be compatible with the exiting high energy light sources such as APS, ESRF and Spring 8. The basic design parameters of PETRA III are given in Table 1.

Table 1: Basic design parameters of PETRA III

Parameter	
Number of insertion devices	13
Energy (GeV)	6
Current (mA)	100
ε_x (nm rad)	1
ε_z (nm rad)	0.01

The number of insertion devices is relatively small for a large machine like PETRA which is due to the fact that the reconstruction should be cost effective. All the insertion devices are undulators. The choice of the energy is a result of the different user demands. Maximum current and emittances are chosen to achieve a high brilliance. Presently a current of 100 mA seems to be a realistic goal. In order not to prevent future upgrades all components of the machine and in particular those which are effected by heat load or radiation should be designed and dimensioned for currents of up to 200 mA.

The machine will be operated in two different modes. It is planned to run with either 960 bunches or with just 40 bunches. Due to the small emittance the Touschek lifetime for the 40 bunch mode would be as small as 2 h incompatible with the user requirements of 24 h. It is therefore intended to run the machine in top up mode which implies rather frequent injection. This measure will also be used in the case of a large number of bunches so that all components that are hit by synchrotron radiation stay in thermal equilibrium. This certainly relaxes the problem of achieving the required photon beam stability.

The reconstruction of the machine will start mid 2007 and last approximately 15 months. After commissioning the hardware of the machine, operation with beam will start at the beginning of 2009. The first synchrotron light for commissioning of the beam lines is expected some six month later.

LAYOUT AND OPTICS

PETRA II consists of eight straight sections that are connected by arcs. The so-called long straights which have a length of 108 m are located in the North, East, South and West. In between two long straights are short straight sections with a length of 64.8m. Long and short straights are connected by arcs. The magnetic structure of the arc is a FODO lattice. At both ends of the arc exists a dispersion suppressor (missing magnet scheme) so that the straights are dispersion free. The part that extends from the middle of one long straight to the middle of the adjacent short straight is the basic building block of the machine. Since this section is just one eighth of the machine it is called an octant. Positrons or electrons are injected in the South-East and travel clockwise around the machine.

New Octant

The thirteen insertion devices are accommodated in one octant of the machine since this is an effective solution in terms of cost and constructional changes. This new octant extends from the North-East to the East of the machine (see Fig.1). The lattice consists of nine double bend achromat (DBA) cells. The length of a cell is 23 m. Eight of the nine cells offer dispersion free straight sections to install insertion devices of up to five meter length.

Figure 1: Site map of DESY with the PETRA storage ring. The new experimental hall is indicated in red.

There are two different cell types, a so-called high beta-x and a low beta-x cell which differ essentially in the value for the horizontal beta-function. In Fig. 2 the optics of the two different cells is shown and table 2 gives the beam sizes and divergences at the positions of the undulators.

Table 2: Optical functions and beam dimensions at the locations of the insertion devices

	5m undulator		2m undulator	
	high β_x	low β_x	high β_x	low β_x
β_x (m)	20.00	1.34	16.15	1.4
β_z (m)	2.39	3.00	2.61	3.00
σ_x (μm)	141	37	127	37
σ_z (μm)	4.9	5.5	5.1	5.5
$\sigma_{x'}$ (μrad)	7	27	8	27
$\sigma_{z'}$ (μrad)	2.1	1.8	2.0	1.8

Since the dispersion in the cells is rather small extremely strong sextupoles will be required to correct the chromatic effect of this octant locally. It turned out that it is more favourable to correct the natural chromaticity of the new octant with the sextupoles in the remaining octants of the machine.

Four of the DBA cells will be equipped with 5 m long undulators whereas in the other four two 2 m long undulators will be installed. In between the two short undulators will be a weak dipole magnet that deflects the beam by 5 mrad. Therefore the beams of these undulators are sufficiently separated at a distance of 50m so that they can be considered independent. In total there are twelve undulators four of 5 m and eight of 2 m length. In addition there will be a 20 m long undulator in the short straight section at the beginning of the new octant.

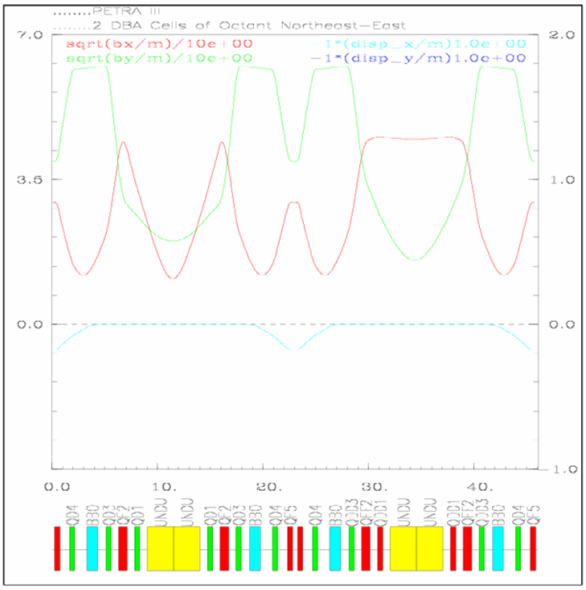

Figure 2: Optical functions for two adjacent DBA cells. Red and green blocks indicate quadrupoles, light blue dipoles and yellow blocks undulators

Old Octants

The magnetic structure of the remaining seven eighth, the so-called old octants, of the machine is not change. The chosen betatron phase advance of the existing FODO lattice of 72° is a compromise between achieving a small emittance and a sufficiently large dynamic aperture. The optics of an old octant is shown in Fig. 3.

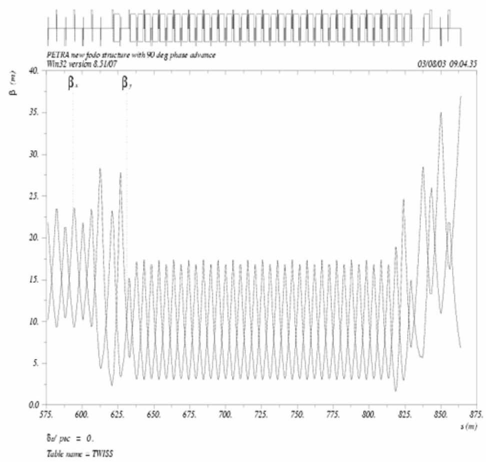

Figure 3: Beta-functions in one of the old octants

As has been mentioned already the chromaticity of the whole ring will be corrected with the sextupoles in the arcs of the old octants. This requires an over-compensation of roughly a factor of two per FODO cell, a value which is also reached in colliders with strong focussing in the interaction regions.

Damping Wiggler Section

The emittance of the combination of the seven old octants and the new octant is roughly 4 nm rad, well above the design goal. Several possibilities have been investigated to reduce the emittance [2].

Finally we decided to use damping wigglers to enhance the radiation damping of the machine and thereby reduce the emittance to the required value. These damping wigglers will be accommodated in the long straight sections in the North and West.

The main parameters of the damping wigglers are given in table 3.

Table 3: Basic parameters of the damping wigglers

Number of wigglers	20
Wiggler length (m)	3.97
Period length (m)	0.2
Peak field (T)	1.52
Magnetic gap (m)	0.24

In between two existing quadrupoles an arrangement of a wiggler, two BPM's and an absorber will be installed (see Fig. 4).

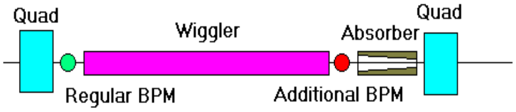

Figure 4: Unit cell of the damping wiggler section

The absorbers of one section have to withstand 500 kW of radiated power. In addition to the absorbers between quadrupoles there will be one large absorber just behind the first dipole of the adjacent arc which has to absorb up to 200 kW. The BPM's are not only necessary for orbit correction but will also be part of a security system. This system has to make sure that the stainless steel vacuum chamber is not hit by synchrotron radiation.

ACCELERATOR PHYSICS ISSUES

Nonlinear Dynamics and Dynamic Aperture

The dynamic aperture of PETRA III has been studied in detail [3]. A sufficiently large horizontal aperture is required for injection. To accommodate the emittance delivered by the booster DESY II (350 nmrad) an aperture of 30 mm mrad is required. It has been shown that the dynamic aperture of the machine is large enough even when including the effects of the damping wigglers and insertion devices. Another important parameter is the momentum acceptance of the machine. It is found that the momentum acceptance is somewhat larger than 1.5 % which accounts for the above mentioned Touschek lifetime of 2 h.

Current Limitations

For the 40 bunch mode a single bunch current of 2.5 mA is required. According to our present understanding of the impedance of PETRA III it should be no problem to store such a current per bunch [4].

The total current of the machine will be limited by coupled bunch instabilities mainly driven by the parasitic modes of the rf cavities [4]. In order to achieve the design current of 100 mA a powerful multi bunch feedback system will be necessary.

Orbit Stability and Tolerances on Optical Parameters

The requirements on orbit stability are rather tight. According to table 2 the limits on orbit stability are 0.5 µm in the vertical and around 4 µm in the horizontal plane at the locations of the insertion devices.

In order to achieve the design goal for the emittances tight tolerances are also imposed on spurious vertical and horizontal dispersion (see table 4).

Table 4: Tolerances on spurious dispersion in the different parts of the machine

	D_x (mm)	D_y (mm)
Wiggler section	18	5
Undulator section	33	7
FODO arcs		58
DBA arcs	22	31

To fulfil the demands on orbit stability and spurious dispersion both slow and fast global orbit feedbacks are necessary. Such systems have been investigated in detail and been proven feasible [5].

REFERENCES

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