A B-Factory in the PETRA Tunnel

F. Willeke for the B-Factory Study Group at DESY
DESY, Notkestr. 85, 2000 Hamburg 52, Germany

I. INTRODUCTION

We report upon a study of an high luminosity asymmetric beauty factory in the PETRA tunnel. The facility consists of two new storage rings of 2304m circumference each which share the tunnel with the PETRA machine. The high energy ring (HER) of the beauty factory will be operated with a beam energy of 9.33GeV and the beam of the low energy ring (LER) has 3.0GeV. In order to obtain a luminosity of

$$\mathcal{L} = 3 \cdot 10^{33} cm^{-2} s^{-1}$$

a beam current of $I = 710mA$ needs to be stored in the HER and the beam current in the LER needs to be as large as $I = 1.1A$. Furthermore vertical β-function values at the interaction point of $\beta_z^*(e^+) = 1cm$ and $\beta_z^*(e^-) = 2cm$ are necessary and a beam-beam tune shift of $\Delta\nu = 0.04$ has to be achieved for both beams. Main parameters of the machine are given in table 1.

Table 1: Main Parameters

	HER	LER
Particles	electrons	positrons
Beam Energy E/GeV	9.33	3.0
Circumference L/m	2304	2304
Harmonic Number	3840	3840
Beam Current I/A	0.71	1.1
Number of Bunches	640	640
Particles per Bunch	$5.28 \cdot 10^{10}$	$8.21 \cdot 10^{10}$
Hor. Emittance $\varepsilon_x/radm$	$0.5 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$
$\varepsilon_z/\varepsilon_x$	0.05	0.05
β_x^*/m	0.40	0.20
β_z^*/m	0.02	0.01
Beam-Beam Tuneshift $\Delta\nu_x$	0.04	0.04
Beam-Beam Tuneshift $\Delta\nu_z$	0.04	0.04
Luminosity $\mathcal{L} = 3 \cdot 10^{33} cm^{-2} s^{-1}$		

The layout of the interaction region has been improved considerably compared to previous designs (see references [2,1,3,4]). A large progress has been achieved in the suppression of synchrotron radiation and the corresponding background problems[4]. There is no change in the rf-system as described in the references quoted above. It still consists of normal conducting one-cell cavities with reduced R/Q and effective HOM damping. The concept of an active damper system has been developed on the base of the $5MHz$ broadband damper system which has been developed for PETRA and HERA and which has been successfully tested in PETRA recently [8].

II Lattice Design

In the design of the interaction region (IR) several conflicting problems have to be solved. The bunches of the two beams have to be merged and separated in a short distance from the interaction point (IP) which allows to distribute the large beam currents over 640 bunches without introducing parasitic bunch crossings. The beams have to be focussed strongly to get small beamsizes at the IP. This is accomplished by magnetic forces so that synchrotron radiation generated in dipole and quadrupole field causes background problems for the detector and cooling problems for the collimator system. The problem is solved the following way: The low energy beam is focused by two low-β tripletts on each side of the IP. There are thus two additional low beta points around the IP. At these low-β points additional quadrupole magnets are placed which focus mainly the high energy beam. These arrangement of lenses focusses the high and the low energy beam simultaneously. For the same values of the β-function at the IP, one obtains the same chromaticity for both beams. The chromaticity for the design parameters does not exceed values of $\xi_z = -88$ which have been achieved earlier in PETRA operation. Chromatic effects can be compensated up to second order using six sextupole families per machine octant. Dynamic aperture has been checked by particle tracking and is found to be sufficient.
The last quadrupole in the second triplett is a $10m$ long combined function magnet which separates the beam vertically by about 100mm. The high energy beam axis is close to the centre of this magnet. In order to obtain early vertical separation, the detector solenoid has to be tilted by $110mr$. The IR quadrupoles are displaced tranversly as to maintain the initial separation at the parasitic crossing points. The sum of linear long range beam-beam tuneshifts caused by the six parasitic crossings amounts to 0.04.

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PETRA has been operated at $17GeV$ operation with a total head-on beam-beam tune shift $\Delta\nu_z = 0.16$ [5]. With electrostatic beam separation at the IP, the long range tuneshift amounted to (extrapolated from measurements in reference[6]) $\Delta\nu_{lr} = 0.036$ which did not cause any noticeable beam blow up.
Fig. 1 shows the arrangement of magnets and the beam separation. The first lowβ quadrupole is a rare earth permanent magnet. The other two quadrupoles of the inner triplett are superconducting. The separator magnet is a Panofski-type combined function magnet. All the other magnets in the lattice are conventional.
The total amount of synchrotron radiation power which is generated upstream of the IP amounts to only $5kW$ from which 60% is absorbed in the interaction region. This does not cause any cooling problem for the synchrotron radiation masks in the IR. The collimator system which consists of four elliptical masks protects the inner $22mm$-radius vertex detetor from primary and secondary photon beams. The power which is absorbed by the silicon layers is in the order of $2 \cdot 10^{-9}W$ which provides a safety margin of two orders of magnitude.
The lattice of the high energy ring is a copy of the PETRA lattice. The arcs of the low energy ring in the arc contain FODO half-cells with a strong, $5.78m$ long dipole magnet ($\rho = 48m$). They are separated by three empty half-cells. This reduces the number of bending magnets by four. In order to provide sufficient radiation damping and to provide the transverse beam emittance of $\varepsilon = 1 \cdot 10^{-7} radm$, six 2m long superconducting wiggler magnets which have an effective field strength of $1.8T$ are needed. The beam emittance can be varied easily over a large range by the size of the dispersion function in these magnets. The longitudinal damping times are then for the high energy beam $21ms$ and for the low energy beam $36ms$. Rf voltages of $U = 17MeV$ and $U = 4.5MeV$ are needed to provide a $1cm$ bunch length in both beams.
The two new rings will be installed on top of each other above the PETRA ring. The old PETRA ring will be left untouched and is serving as an injector for HERA. Fig 2 shows a cross section of the tunnel in a regular arc section. The rf section will be placed in the former experimental halls where there is sufficient room for waveguides, tuners and higher order mode couplers.

III High Beam Currents

The large beam currents of $1.1A$ for positrons and $0.71A$ for electrons are distributed over 640 bunches. No probelms are expected for the resulting single bunch currents of $\simeq (1.1 - 1.6)mA$ concerning single bunch stability. The central problem in storing the high currents is connected with the coupled bunch instabilities. They can only be controlled by a broadband active damper system.
To keep the effort in reasonable limits, it is important to increase the threshold currents as far as possible by damping the parasitic modes of the rf resonantors and by providing sufficient natural damping in the beam.
In the low energy ring, 9 single-cell-$1GHz$-cavities provide a voltage of $4.5MV$ which is necessary for a bunch length of $1cm$. The total rf power needed for $1A$ beam current is $P = 1.04MW$. Given the HOM-spectrum of the passively damped cavities described in reference[7], the treshold current for the longitudinal dipolar multibunch instability amounts to $I_{tr} = 52mA$. This was calculated for a radiation damping time of $36ms$.
For the high energy ring, 31 single cell $500MHz$ cavities are needed to generate a circumferencial voltage of $16.5MV$ which determines the $1cm$ bunchlength. The threshold current for the longitudinal dipolar multibunch current instability is calculated for a radiation damping time of $21ms$ which yields $78mA$.
For these thresholds of instability for the two machines it turns out that the natural damping must be reduced to about 500 μsec in order to suppress the instability for the design currents. Thus the machines will be operated a factor 20 above the threshold currents. In the case of PETRA storage ring, it has been demonstrated recently [8] that this is possible for a bandwidth around 5 MHz.

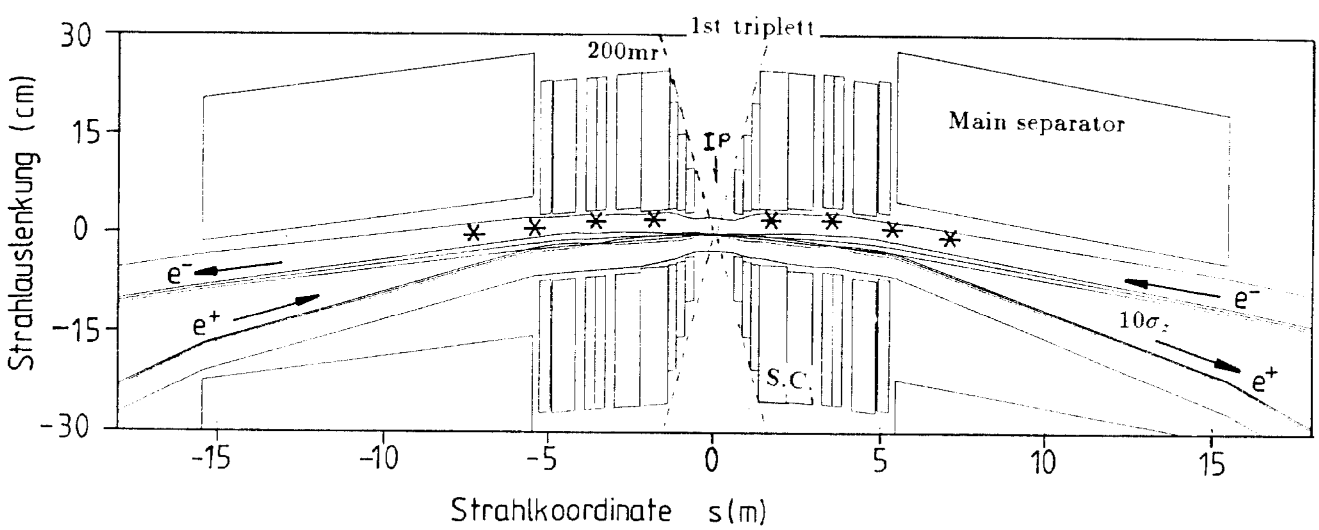

Figure 2: Layout of the Interaction Region (Side View) and the vertical Beam Separation

Due to the high number of bunches (640), the bandwidth of the feedback system for the asymmetric collider has to be around 40 MHz.
The feedback gain necessary to damp the transverse and longitudinal oscillations in the injection process determine the required voltage in the longitudinal and the kicker strength in the transverse direction respectively.
The difference between the proposed system and the excisting PETRA-broadband feedback system is connected with the required large bandwidth of the deflecting and accelerating devices. For the PETRA system, the deflecting kicker was built up as a ferrite-capacitor loaded delay line together with a strip chamber to protect the ferrite material against beam induced wall currents. The advantage of such a device is the high field which can be achieved for a moderate input power. Its disadvantage is the limited bandwidth. For the proposed system, the kicker magnets do not contain any ferrite but have a sufficiently broadband frequency response. A series of kicker-amplifier provides the needed deflection.
In order to damp dipole oscillations in the longitudinal direction an overlapping cascade of five $750MHz$-klystrons will be used. They are operated in a single sideband amplitude modulation mode with a bandwith of $\Delta f = 8MHz$ each.
A large effort is also needed for the digital signal processing. The pick-up and the detector electronics of the PETRA feedback systems have a bandwidth of about 40 MHz. They can be carried over to the proposed system with only little modification. Eight digital filters will be used in parallel.
If one has to operate a feedback system more than a factor of 20 above threshold, damping is not sufficient.
Although the beam modes are all damped (asymptotically), depending on the actual instability configuration, the damping rates and frequency shifts of different modes become different. This leads to overshoot phenomena of the beam or - equivalently - makes the beam extremely sensitive against noise. Therefore instead of providing only damping one has to build up a mode-related adaptive digital filter system for the compensation of the beam mode related impedance.

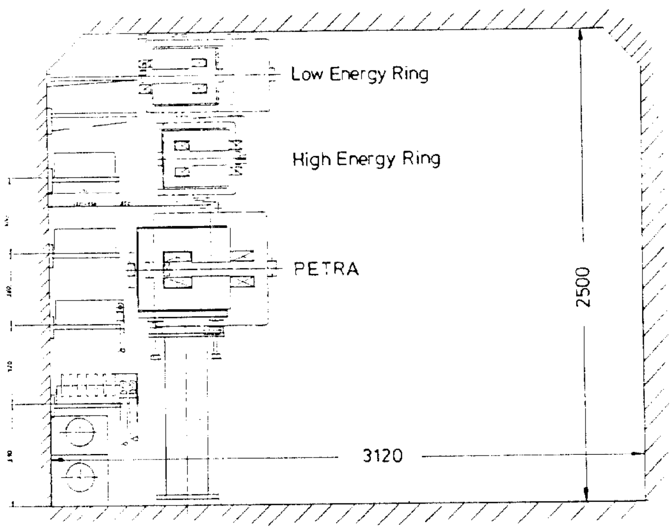

Figure 1: Cross Section of the PETRA Tunnel with the Asymmetric Collider Magnets

III Summary

A design of an asymmetric beauty factory which should provide a luminosity of $3 \cdot 10^{33} cm^{-2} s^{-1}$ is in progress. A satisfactory solution for layout of the IR has been found. The synchrotron radiation background should be much smaller than the tolerable level. The rf system is based on normal conducting cavities. Effective higher order mode damping in the cavities limits the growth time of multibunch instablities. The concept of a broadband feedback system has been developed to control multibunch instabilities.

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