THE VACUUM SYSTEM FOR PETRA III

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Abstract

It is planned to rebuild the storage ringe PETRA II, presently used as pre-accelerator of HERA, into a high performance synchrotron light source. By making use of the large circumference and the installation of damping wigglers it will be possible to achieve exceptionally small emittances in the new storage ring.

The requirements for the vacuum system are more advanced for the new storage ring as well. Besides the goal to achieve low pressures and fast conditioning times a major key for the new ring is a very high orbit stability which implies high thermal stability of BPM's and other vacuum components. We describe the basic concepts for chamber layout, pumping schemes, synchrotron radiation absorption and mechanical stability for the standard arcs and the experimental octant. Furthermore the expected performance will be discussed.

OVERVIEW AND PARAMETERS

Table 1: Selected beam parameters and synchrotron radiation properties for dipole radiation (power, critical energy, photon rate) in the standard arc and the new experimental octant.

circumference: 2304 m		
energy: 6 GeV	current: 100 mA	
hor. emittance: 1 nm rad	coupling: 1 %	
arc dipole, ρ = 195m		
P' = 48W/m	E_c = 2.5 keV	$n_\gamma = 4 \cdot 10^{17}\,\mathrm{m^{-1}s^{-1}}$
experimental octant dipole, ρ = 23m		
P' = 3.5 kW/m	E_c = 21 keV	$n_\gamma = 3.4 \cdot 10^{18}\,\mathrm{m^{-1}s^{-1}}$

Presently the 25 year old PETRA accelerator is equipped with aluminium chambers and integrated ion getter pumps that use the magnetic field of the dipole magnets. The accelerator was initially laid out for an electron current of a few mA and an energy of 23 GeV. Today it is used to deliver electrons of 12 GeV and protons of 40 GeV to HERA. The proton RF system as well as proton injection and ejection elements will be superfluous after the rebuild and will be removed. We distinguish here two sections of the accelerator - the old 7 octants that keep the magnet arrangement but will be equipped with a new vacuum system, and the new octant with short new dipoles and the undulator insertions. Major parts of the system as the dipole chambers will be build from aluminium, but steel and copper will be used as well. There is a third new section to be build with about 80 m active length of damping wiggler magnets. The damping wigglers will be installed in two groups with 10 wiggler magnets each. In each of these sections an amount of roughly 450kW synchrotron radiation is produced. The safe handling and absorption of the strong radiation fan in the presence of orbit- and alignment imperfections is a major issue for the design of the vacuum system in these regions. The layout of this section (see [1]) is presently investigated by colleagues from Novosibirsk and is therefore not discussed here.

VACUUM REQUIREMENTS AND CONDITIONING

The contribution of beam-gas scattering to to the beam lifetime should not be stronger than contributions by other beam dynamics effects. The Touschek effect imposes a lifetime of roughly 50 hours. For estimating the maximally acceptable pressure two lifetime limiting effects have been considered – elastic Coulomb scattering and inelastic Bremsstrahlung interactions. We assume a residual gas composition of 25% CO and 75% H_2. For inelastic scattering the beam lifetime is given by:

$$\tau_{\mathrm{inel}}\left[\mathrm{h}\right] = \frac{-0.695}{\ln\left(\delta E\right)\ \sum_i \frac{P_i\left[\mathrm{pbar}\right]}{X_{0,i}\left[\mathrm{m}\right]}}$$

Here δE=1.5% is the energy acceptance, $X_{0,\mathrm{i}}$ the radiation length of gas i under standard conditions, and P_i the corresponding partial pressure. With a total pressure of $2 \cdot 10^{-9}$mbar one obtains a lifetime of 94 hours which would be sufficient. The contribution from elastic scattering turns out to be 660 hours and is therefore not significant. As usual for electron storage rings the vacuum pressure in PETRA III will be dominated by synchrotron radiation induced desorption. Due to conditioning the photo desorption rate will decrease continuously with time-integrated beam current. The important question concerns the required conditioning time after which the anticipated vacuum quality is achieved. The dynamic pressure in a synchrotron radiation dominated vacuum system is roughly given by the following relation:

$$P = \frac{R_0 T}{N_A}\ \frac{\dot{n}_m}{S'} = \frac{R_0 T}{N_A}\ \frac{\eta(n_\gamma)\ \dot{n}_\gamma}{S'}$$

Here P is the pressure, R_0 the gas constant, N_A Avogadro's Number, $\dot{n}_m$ the rate of molecules released from the wall per unit length and S' the pumping speed per unit length. The desorption coefficient η denotes the number of gas molecules released from the wall per incident photon. The desorption coefficient decreases with the irradiation of the material. Detailed measurements exist on the mechanism of synchrotron radiation conditioning, e.g. in [2]. As a function of the

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integrated photon dose per unit length n_γ the desorption coefficient decreases first very slowly, while it starts to fall roughly inversely proportional to the dose for higher doses. A simplified parameterization of this behaviour is formulated as follows:

$$\eta(n_\gamma) = \begin{cases} \eta_0 & \text{for } n_\gamma < n_{\gamma 0} \\ \eta_0 \dfrac{n_{\gamma 0}}{n_\gamma} & \text{for } n_\gamma > n_{\gamma 0}. \end{cases}$$

The constants can be estimated from the measurements in [1] with $\eta_0 \approx 9 \cdot 10^{-2}$, $n_{\gamma 0} \approx 5 \cdot 10^{19}$ m^{-1}. Considering the pressure reached after a reasonable conditioning time one has to realize that this pressure is practically independent of the typical instantaneous photon rate and consequently the stored current. Presuming the usual operating current is not changed over time, the quotient of instantaneous photon rate and integrated dose is a constant for a fixed conditioning time. Furthermore the achievable pumping speed per unit length is limited by geometry and reaches similar values in any accelerator. In practice one observes operating pressures in the same order of magnitude in accelerators with very different photon fluxes as for example LEP [3] and PEP-II [4].

Taking into account conductance limitations we expect an average pumping speed of 60 $ls^{-1}m^{-1}$ in PETRA III. In order to reach the required $2 \cdot 10^{-9}$ mbar the system has to be conditioned until $\eta < 6 \cdot 10^{-6}$. From that and the radiation specific numbers in table 1 we compute the necessary integrated current to 60 Ah. This value is expected to be reached after 800 operating hours with 75 mA beam current on average.

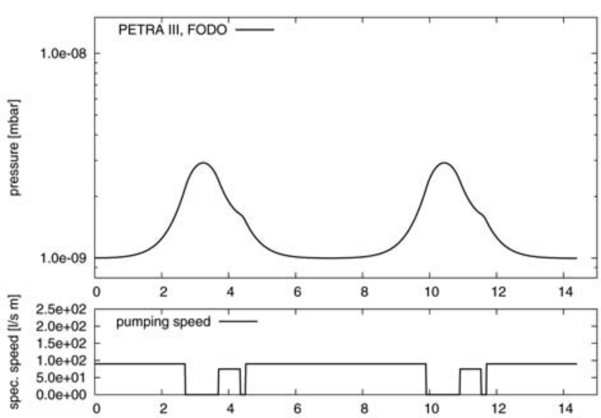

Figure 1: Estimated pressure profile for $\eta = 6 \cdot 10^{-6}$ in the standard arc.

LAYOUT OF THE STANDARD ARC

The term standard arc refers to the 7 octants that keep the magnet arrangement from PETRA II but will be equipped with new vacuum chambers. The dipole chambers will be manufactured from an extruded aluminium profile. They will be equipped with internal NEG-strip pumps, water cooling channels on both sides and stainless steel flanges. At 2.5keV critical energy the wall thickness of the aluminium chamber represents several hundred attenuation lengths for the synchrotron radiation. Consequently no additional shielding is necessary for sensitive components in the tunnel. The option of an ante-chamber design was discussed in detail during the conceptional design phase, but was finally dropped in favour of simplicity. The idea of the ante-chamber is to separate surfaces irradiated by synchrotron radiation from the beam vacuum to achieve lower pressures for the beam. However, even in an ante-chamber it is impossible to avoid stray light in the beam vacuum, although it may be suppressed by two orders of magnitude as compared to the direct radiation. The surfaces that receive stray radiation will be hit by less photons but will also be less conditioned. Since the quotient of instantaneous rate and integrated dose is constant for a fixed conditioning time there will still be significant outgassing in an ante-chamber.

A quadrupol and sextupol magnet as well as a BPM and the mechanical support of the vacuum chambers are situated in-between two dipole magnets. In these magnets the chamber is made from stainless steel with an elliptical cross section of $80 \times 40 mm^2$.

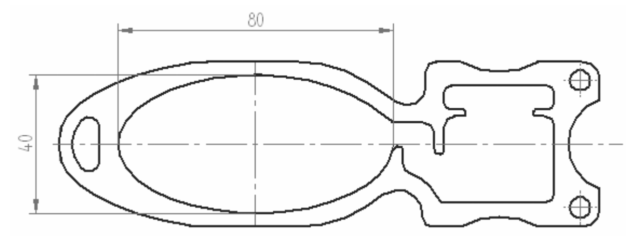

Figure 2: Cross section of the dipole chamber. Synchrotron radiation is absorbed on the left side. The NEG strip is located in the right handed side channel.

NEW OCTANT

The new octant is divided into 8 DBA cells and contains the insertion devices. The undulators are 5m long and 5 of them are split in two halves with a small tilt angle against each other. The dipole magnets are much stronger than those in the standard arc (compare table 1). Consequently the radiation is harder and more power is produced. An overview of a single DBA cell is shown in Fig. 3.

Figure 3: DBA cell with split undulator in the center.

In order to maximize the thermal stability and to accommodate circulating beam, dipole radiation and outgoing undulator radiation-beams, wide vacuum chambers and local copper absorbers for the dipole radiation will be used. To achieve the required strength we use stainless steel chambers with 4mm wall thickness and varying cross section along the longitudinal dimension. The chambers will incorporate distributed NEG pumps. An example is shown in Fig. 4.

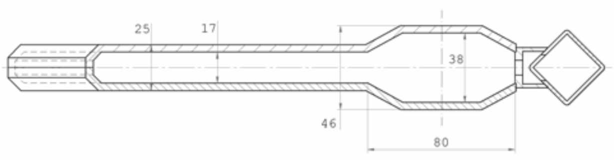

Figure 4: Cross section of steel chamber in new octant. The NEG pumping channel is located on the right side.

The absorbers will be manufactured from massive copper blocks by wire EDM. The shapes are moderately tapered to minimize higher order mode excitation. They are water cooled and take a power load of 3-5 kW each. Some absorbers exhibit two downstream openings for the particle beam and one or two undulator beams (Fig. 5).

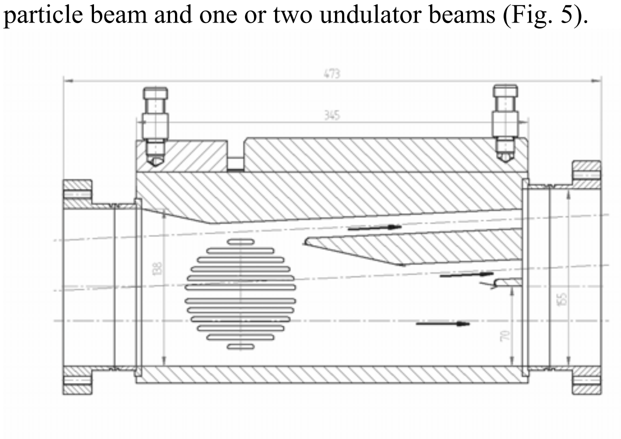

Figure 5: Copper absorber for dipole radiation with three openings for two undulator beams and the circulating particle beam.

The undulator chambers represent a special problem. A magnetic gap height of 9.5mm is anticipated for the undulator magnets. With a minimum wall thickness of 1mm and mechanical tolerance of 0.5mm the remaining vertical aperture amounts to 7mm which is just enough for the beam. Several options concerning the choice of the chamber material have been discussed. Finally an extruded aluminium profile was chosen. The major advantage of this choice is the excellent heat conductivity which is important if dipole radiation hits the chamber wall, and the simplicity of the production process with relatively complicated cross-sections. The disadvantages are the higher outgassing, for example compared to steel, the lower mechanical stability and the requirement of cost intensive aluminium-steel transitions at the ends. As typical for such narrow vacuum chambers the vacuum conductance is poor which in turn results in the need for an integrated pump. In general the residual gas pressure in the undulator is critical since it causes Bremsstrahlung background for the experiments. Here we are considering two options – NEG coating of the inner surface with a simple elliptical geometry, or pumping by a NEG strip in a side channel. The NEG coating is probably more effective and allows for a simple chamber design, but requires the chamber to be heated to 200°C in situ. The resulting expansion in length of more than one centimetre has to be compensated with a special bellows insertion. However, this requires more space in longitudinal direction and compromises the stability of adjacent BPM's which are important for the orbit feedback and the stability of the undulator beam. Also the required removal of the undulator magnets during the activation process presents a drawback. Because of these considerations a preference has been developed for the NEG strip version, although the NEG coated version will be developed further as an alternative or possible upgrade.

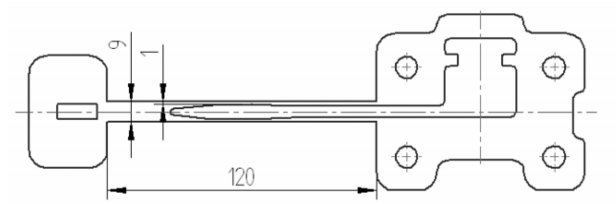

Figure 6: Cross section of the proposed wiggler chamber. The NEG pumping channel is visible on the right side.

STATUS AND PLANS

At present the design of the standard octants is practically finished and we are in process of ordering the components. Manufacturing of the chambers will start in 2006. It is planned to install a set of two prototype chambers in PETRA II still within this year. The goal is to investigate thermal stability of the BPM's and possible HOM excitation in the NEG pumping channel of the dipole chamber. The new octant is still in the design phase. The available space is tight in these sections and the design has to undergo several iterations to meet the requirements of the magnet design, instrumentation, surveying and vacuum system layout in a coherent way. Dismantling of PETRA II and the rebuild will start in mid 2007. The new PETRA III should be operable by the end of 2008.

REFERENCES

[1] PETRA III Technical Design Report, DESY 2004-035
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