Vacuum System Design of the Third Generation Synchrotron Radiation Source PETRA III

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Abstract. Within the next two years the 2.3 km long storage ring PETRA will be rebuild into one of the most brilliant x-ray sources worldwide (PETRA III). The large bending radius and the use of damping wigglers allow to achieve small beam emittances and extremely brilliant x-ray beams. In this paper we describe the design and the expected performance of the vacuum system for the storage ring. It consists of standard arc sections, an experimental octant which is equipped with undulators and several straight sections that include the damping wigglers. Because of the long length of the storage ring a cost effective solution had to be found. Besides the requirement to quickly provide acceptable residual gas pressures the technical challenges of the system include the provision of high thermal stability with respect to magnets and BPM's, and the design of thin walled insertion device chambers as well as high power synchrotron radiation absorbers.

1. Introduction

In the last few decades synchrotron radiation has become an important tool for basic as well as for applied sciences. The main domain of 3rd generation synchrotron radiation sources is the investigation of small samples or sample regions in the sub µm range. The required high brightness of this kind of light sources is delivered by small emittances and high beam currents. PETRA is a 2304 m long storage ring located at DESY in Hamburg and was initially used as an electron positron collider. Later on it was converted into a pre-accelerator for the proton electron collider HERA. After its reconstruction PETRA III will become a low emittance 3rd generation light source (ε_x=1 nmrad) at an energy of 6 GeV and an initial current of 100 mA [1]. Therefore one eight of the ring will be completely new designed (Double Bending Achromat cells) to hold the insertion devices while seven eights keep their magnetic structure (periodic FODO cells). The vacuum system for all parts of the ring is new designed to fulfill the demands concerning power absorption and beam lifetime as well as thermal and mechanical stability.

2. Vacuum chamber design

The vacuum system design is determined by the needed background pressure, the required mechanical stability, the power of synchrotron radiation which has to be absorbed and the cost effectiveness. As the magnetic structure and the function of the seven eights and the new octants are very different the

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choice of chamber material, geometry, absorbers and the pump speed distribution for these two parts of the storage ring are distinct too.

2.1. The seven old octants

The FODO cell consists of a periodic arrangement of a dipole, a quadrupole and a sextupole followed by the same arrangement with the only difference that the second quadrupole is focusing in the other transversal direction. Between the quadrupoles and the sextupoles a beam position monitor is placed. The dipole chambers are made of a 5.8 m long aluminum profile with an elliptical (80x40 mm²) cross section and 200 m bending radius (see figure 1). Since the synchrotron radiation and hence the photon induced outgassing is distributed over 5 m length a NEG strip with an uniformly distributed pumping speed is installed in a side channel of the aluminum profile. At the end of each chamber a sputter ion pump with a pumping speed of 60 l/s is connected. It pumps noble gases and other residual gases as well which are not pumped by the NEG strips. To maintain thermal stability the profile contains three water cooling channels. The one at the outer side compensates the heating due to synchrotron radiation and the two at the inner side deliver cooling when the NEG strips are activated. The water cooling channels are also used when the chambers are bake out prior to installation by applying hot steam (150°C) to the cooling channels. The 1.3 m long quadrupole chambers are made of stainless steel with 4 mm wall thickness to ensure very good thermal and mechanical stability for the integrated beam position monitors. These water cooled chambers are equipped with a NEG strip in a brazed channel (see figure 1).

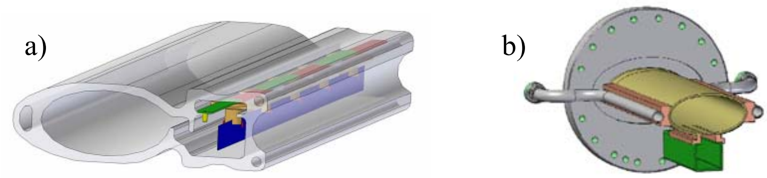

Figure 1: Aluminum dipole chamber with the NEG strip in the side channel (a) and cross section of the stainless steel chamber in the quadrupoles (b).

2.2. The new octant

The vacuum system in the new octant is mainly build from keyhole shaped stainless steel chambers as shown in figure 2. The wall thickness is 4 mm. NEG strips are placed in brazed side channels which are connected to the chamber by rectangular pumping slots all over the length. Since the stainless steel chamber should have best thermal and mechanical stability no synchrotron radiation may hit the chamber walls. The keyhole shape was chosen to deliver enough space for the electron beam and for the synchrotron radiation as well. The dipole magnets in the new octant of PETRA III are stronger than the ones in the old octants. Therefore the intensity of the emitted synchrotron radiation is much higher and can reach 3.5 kW per magnet at 100 mA beam current. It will be absorbed by massive water cooled copper blocks (figure 2). To avoid pressure rise by means of photon induced desorption at these absorbers a sputter ion and a titanium sublimation pump is placed close to them. With this pumping speed the pressure will remain at acceptable values even at full radiation load (see section 4).

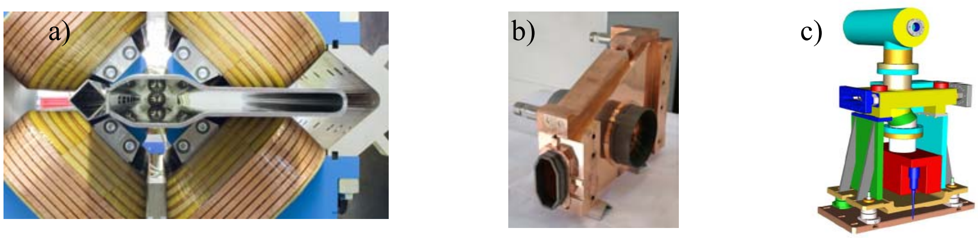

Figure 2: Keyhole shaped stainless steel chamber installed in a quadrupole magnet (a), massive copper absorber for the radiation from the strong dipoles (b) and CAD model of a complete assembled absorber with titanium sublimation and sputter ion pump (c).

The experimental section of PETRA III is equipped with 9 insertion devices. As the beam position in the undulators is extremly critical beam position monitor are placed next to them. The space in the undulator sections is strongly limited and the beam position monitors have to be directly connected to the undulator vacuum chambers without using bellows. These chambers therefore have to combine extreme mechanical stability and a small wall thickness because of the small undulator gap. They are made of an extruded aluminum profile with an elliptical shape (7x57 mm) and a side channel for two NEG strips (figure 3). Additionally there are 4 sputter ion pumps connected. For thermal stability they are water cooled and not directly hit by synchrotron radiation. To achieve the required mechanical stability the profile is clamped to a stiff support bar.

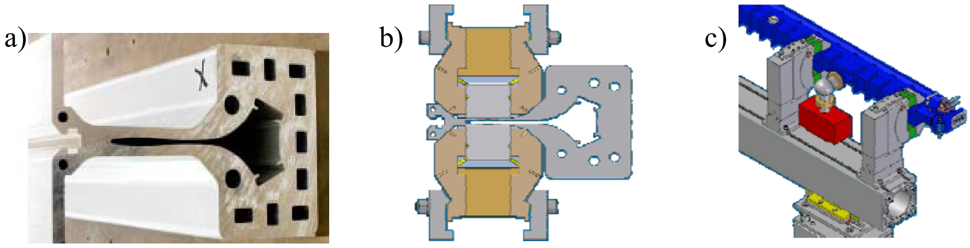

Figure 3: Vacuum chamber profile in the undulators (a), CAD model of the installed chamber (b) and vacuum chamber clamped to the support bar (c)

3. Synchrotron radiation and photon induced desorption

When subjected to synchrotron radiation the photon induced desorption from the chamber walls can exceed the thermal outgassing by far and it is this effect which determines the vacuum performance of the storage ring. The gas desorption coefficient η describes how many molecules are released from the wall per incoming photon. For different kind of molecules it depends on the material which is irradiated, the photon dose and the history of the material. If metal is exposed to high photon doses η will decrease. The coefficient can be roughly estimated from measurements [2]. For high photon doses η is interpolated by assuming that its decrease is proportional to the inverse of the photon dose. An experimental study with the new chamber design which was installed in PERTA II showed that this assumption is valid.

The radiation from the bending magnets in the old octants of the PETRA III ring hits directly the aluminum and stainless steel chambers. Every dipole produces 258 W synchrotron radiation (100 mA) which corresponds to $2.13 \cdot 10^{18}$ photons per second with a critical energy of 2.45 keV and a photon rate per length of $4 \cdot 10^{17}$ ph/m. The power is distributed over 5 m so the power density is rather low and in combination with the water cooling no constitutive heating of the chamber walls will occur. The situation in the new octant is more complicated since the dipole magnets are much stronger there. Each one produces 3500 W synchrotron radiation which is absorbed at special copper absorbers as shown above. The geometry of the system is designed in a way that no synchrotron radiation can hit the chamber itself. The number of photons emitted per second is $3.4 \cdot 10^{18}$ and the critical energy is 20.9 keV.

4. Expected performance and pressure profiles

The measured values for η are used to calculate the expected pressure profiles of the periodic FODO cell and the DBA cell of PETRA III. The pressure profile of the FODO cell is calculated for different conditioning times. Therefore an analysis of the spatial distribution of the synchrotron radiation was made. With the power density of the radiation and the outgassing coefficients the additional gas load was calculated. It was taken into account that the conditioning is different for different metals and gases. That’s why the pressure profile not only has lower pressure values but also changes its shape during conditioning (see figure 4b). The average pressure after 100 A·hr conditioning is $1.4 \cdot 10^{-9}$ mbar. Without synchrotron radiation the pressure profile is determined by the thermal outgassing of the metals and reaches an average pressure of $3.9 \cdot 10^{-10}$ mbar with assumed outgassing rates of $2 \cdot 10^{-11}$ mbar·l/s·cm^2 for aluminum and $2 \cdot 10^{-12}$ mbar·l/s·cm^2 for stainless steel.

A pressure profile was also calculated for a complete DBA cell. As the chambers there change their cross section in the longitudinal direction the calculations were done with an average value. Without radiation the average pressure is $1.1 \cdot 10^{-10}$ mbar and with 100 mA beam current after 100 Ahr conditioning it is $2.3 \cdot 10^{-10}$ mbar. For these calculations the code Calcvac [3] was used. Since these structures are periodic in the storage ring periodic boundary conditions were used to calculate the profiles.

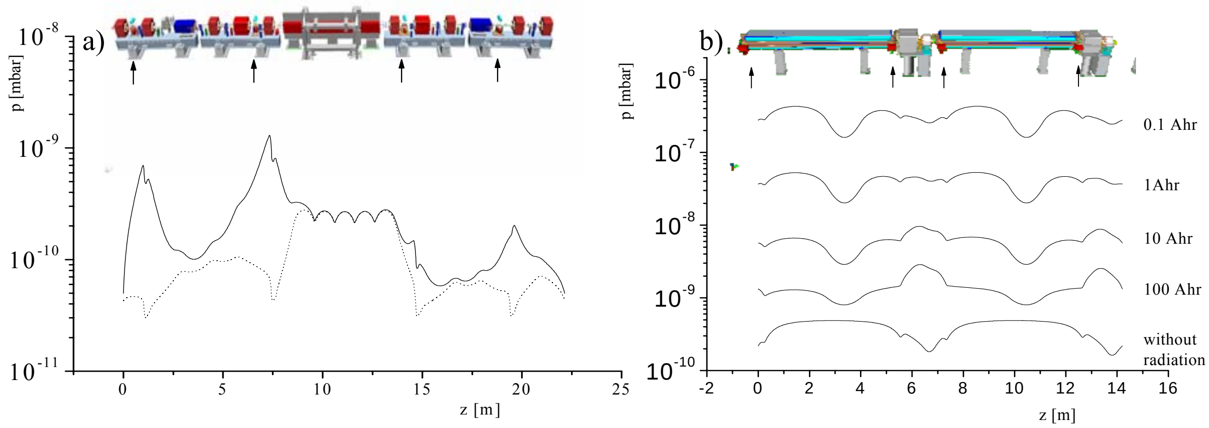

Figure 4: Pressure distribution along a DBA cell with undulator (a) and along a FODO cell (b), the arrows indicate the position of the high power absorber (a) and of the sputter ion pumps (b). The direction of the beam is from left to right in both graphics

The dashed line in figure 4a indicates the pressure profile for a DBA cell without beam and the solid line for 100 mA beam current after 100 Ahr conditioning. At the absorbers the pressure reaches the lowest values without beam due to the high pumping speed. Under operation with 100 mA beam current the photon induced desorption leads to a localized increase of the pressure at the absorbers. The periodic structure in the middle is the undulator whose pressure distribution is not very much affected by the presence of the beam as no synchrotron radiation will hit the chamber.

5. Conclusion

The construction of the PETRA III vacuum system is at an intensely active period marked by ongoing development, manufacturing and testing. The analysis indicates that the vacuum system designed for PETRA III meets the required performance specifications. After 100 Ahr conditioning the expected residual background pressure in the seven eights and in the new octant as well will enable adequate beam life times. While in the FODO cells the pressure distribution is rather smooth, in the new octant it has high pressure values at the absorbers and very low values between them. The absorption of synchrotron radiation at the water cooled chamber walls and at the high power absorbers will provide the required thermal and mechanical stability. The delicate undulator vacuum chamber won´t be hit by synchrotron radiation and therefore neither the thermal stability nor the expected background pressure in it will cause any problems.

The assembly of the new vacuum system will start in the second half of 2007 and is planed to be finished in 2008.

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