FIRST OPERATIONAL EXPERIENCE WITH THE 2.3 KM LONG UHV SYSTEM OF THE ELECTRON STORAGE RING PETRA

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Abstract

The UHV system of PETRA is divided by gate valves into 30 separate sections of about 100 m length, each provided with a turbomolecular pump and a mass spectrometer. The vacuum chambers in the arcs are made from aluminium extrusions, and the straight sections from stainless steel. The installed mean pumping speed is about 110 l/s/m. The discharge current of the sputter- ion pumps is used to monitor the pressure of the system. All active vacuum components such as pumps, spectrometers, valves, turbomolecular pumps etc., are computer controlled over distances of the order of 1 km. A base pressure lower than 1x10⁻ mbar is obtained without bake-out. Also an Argon glow discharge cleaning in situ is not needed because of the self cleaning effect of the synchrotron light emitted by the circulating electrons. Pressure increases of about of 1x10⁻ mbar per stored mA and beam life times of the order of 20 hours have been achieved up to energies of 18 GeV.

1. Introduction

The world's biggest 19 GeV electron-positron storage ring PETRA 1,2 , built at DESY 3 in Hamburg, is under operation since summer 1978. PETRA has a circumference of 2.3 km.
Physics experiments with storage rings require a beam life time of several hours. This is only possible if the residual gas pressure along the beam path is below 10⁻ mbar 4 . This vacuum range, in fact even down to 10⁻ mbar, is achieved more or less routinely 5 .
For electron storage rings, however, it is more difficult to obtain these low pressures. This is due to the synchrotron light radiated by the electrons in the arcs of the accelerator. For PETRA, the radiated power amounts to up to 3.5 MW, which results in a linear thermal load of 1.7 KW/m. Therefore the vacuum chambers must be water cooled. The spectral distribution of the synchrotron light is described by the critical energy $_c$ in keV 4 :

$$ {}_c = \frac{2.218\ E^3}{R} , \qquad (1) $$

where E is the beam energy in GeV, and R the bending radius in m. For PETRA, $_c$ varies from 1.44 keV at 5 GeV to 97.2 keV at 19 GeV. The synchrotron light spectrum extends from infrared up to photon energies of about five times the critical energy. Due to the interaction of the synchrotron light with the chamber surfaces an additional gas desorption results, which is normally higher than the thermal gas desorption.

The resulting outgasing rate Q_{Phe} in mbar.l/s is given by 4 :

$$Q_{Phe} = 5 \times 10^{-4} \; I_{Phe} \quad , \qquad (2)$$

where I_{Phe} is the synchrotron light induced photoelectron current in mA, and the electron impact desorption coefficient in molecules/electron. The electron impact desorption coefficient can be reduced during the bombardment of the chamber walls by the photoelectrons. The dependence of on the photoelectron dose D Ah/cm can be described for normally cleaned vacuum chambers by the empirical equation 4 :

$$= 4.8 \times 10^{-7} D^{-0.63} \qquad (3)$$

A significant part of the synchrotron light spectrum penetrates the vacuum chamber walls by Compton-scattering, and can cause radiation damages to the magnet coil . Typically for PETRA, about 33 % of the synchrotron light power at 18 GeV escapes through the vacuum chamber. The vacuum chambers have therefore to be covered with 3 mm lead in order to reduce the radiation level.

Another problem arises from the high bunch currents of PETRA, which can excite parasitic rf modes at places where the chamber cross-section changes. The beam energy losses to parasitic modes can cause beam instabilities or catastrophic overheating of vacuum components. Only a "smooth" vacuum system, without steps and irregularities in the chamber shape and in the connections between the chambers, can reduce these losses to an acceptable level.
In the following sections the PETRA vacuum system and the vacuum controls will be described. Finally the first operational performance will be presented.

2. The PETRA Vacuum System

The PETRA vacuum system is divided by gate valves into 30 vacuum sections each having a length of about 100 m. This length results from an optimal balance between costs, geometric considerations, and short pumpdown and leak-detection times. The gate valves are viton sealed, bakeable up to 150°C and specially designed in order to reduce the rf parasitic mode losses 6 . Each vacuum section is provided with a Pirani gauge, a quadrupol mass spectrometer, and a turbomolecular pump. The discharge current of the sputter-ion pumps serves as pressure monitor. The standard vacuum chambers of the 1800 m long arcs are made from extrusions of the aluminium alloy AlMgSi 0.5. These extrusions have a four-channel cross section to accept respectively the beam, the integrated sputter-ion pumps, the water cooling and the bake-out elements (Fig. 1). The standard chambers are produced in lengths of 7.2 m. About 5.3 m of this length lies in the bending field and it is provided with integrated sputter-ion pumps 7, 8 . They have a mean linear pumping speed of 110 l/s/m after bake-out,or 60 l/s/m without bake-out. Over the length of the bending magnets the wall between the beam and pump channels is perforated by using a spark erosion technique 7 . In the region of the quadrupoles and sextupoles the wall remains imperforated and the pump channel is cut off, so that the bore of these magnets can be

Fig. 1: Cross-section of the PETRA extrusions consisting of four channels for the integrated sputter-ion pumps, beam, water cooling and heating pipe.

Fig. 2: Transition between two chambers. Finger contacts between the sliding surfaces give a "smooth" rf transition.

kept small. All the needed aluminium-to-stainless steel vacuum transitions in PETRA are made by two novel techniques developed at DESY 7, 9 . Each end of a standard vacuum chamber is provided with a stainless steel collar which is used to connect the chambers by in-situ welding 7 of a bellow between the collars (Fig.2). The rf "smooth" transition between two chambers is achieved by using finger contacts between the sliding surfaces of the chamber ends (Fig. 2). The standard chambers are cleaned by normal chemical treatment. The final cleaning is achieved in the laboratory by an Argon glow discharge and a bake-out at 150°C.
The vacuum chambers of the long straight sections (4 x 90 m) are mainly made from stainless steel and they are provided with water cooling in order to avoid heating from rf parasitic mode losses.
The relatively complicated vacuum chambers of the short experimental straight sections (4 x 40 m) are also mainly made from stainless steel using standard fabrication techniques.

Fig. 3: Overview of the PETRA pressure distribution

Fig. 4: Mass spectrum of a PETRA vacuum section

3. The PETRA Vacuum Controls

The vacuum control system has to handle about 1000 active components such as sputter-ion pumps, valves, mass spectrometers etc. The electronic equipment of these components is distributed in the 8 halls around the ring. Every active vacuum component is directly connected with its electronic equipment in the hall. The hall substations are connected to the computers in the central control room via the Serial Data Acquisition and Control system SEDAC 10 . Normally, an overview of the vacuum pressures is displayed, which is updated at regular intervals (Fig. 3). Using tracker ball and cursor the operator can manipulate individually or collectively the vacuum components. This system allows the operation of the mass spectrometers directly from the control room (Fig. 4).

4. Performance of the PETRA Vacuum System

The 1 1/2 year operational experience with PETRA has shown that the needed performance for the vacuum system can be achieved without bake-out and Argon-glow-discharge-cleaning in situ. A base pressure without beam of lower than 10 mbar can be established in a time of less than 2 weeks after venting the vacuum system with pure Nitrogen for modifications and repairs. This recovery time can be further reduced up to 10 hours in cases when only small components must be replaced.
In the first months of operation, the pressure increase with beam reached a value of about $1 \times 10^{-}$ mbar/mA, which is further reduced to about $1 \times 10^{-}$ mbar/mA during the experimental runs of PETRA. The latter value can also be recovered in a short time after venting the vacuum system with pure Nitrogen. Assuming a linear pumping speed of 60 l/s/m for the unbaked vacuum system and a photoelectron current of 1.45 mA/m/mA at 18 GeV, equation (3) results in $n = 8.3 \times 10^{-}$ molecules/photoelectron. Beam life times of up to 20 hours have been measured in the total energy range of PETRA.

5. References

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