INTERACTION REGION VACUUM SYSTEM DESIGN AT THE PEP-II *B* FACTORY

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Abstract

The Interaction Region Vacuum System in the PEP-II *B*-Factory at SLAC must produce average pressures in the 10^{-10} Torr range. Low beamline pressures will minimize the background radiation encountered by the BaBar Detector. A combination of copper and stainless steel vacuum chambers with continuous antechambers are used to make up the beam tubes. Linear Non-Evaporable Getter (NEG) pumps are used to produce distributed pumping along the length of these beam tubes. High conductance "microwave" type screens provide RF shields between the beam aperture and the NEG pumps. In this paper the design features of the beam tubes, NEG pumps, and RF pump screens are described and the vacuum and impedance analyses conducted in support of the design are discussed.

1 INTRODUCTION

The Interaction Region (IR) is the heart of the PEP-II storage ring. Since the BaBar Detector is located at the IR there is a more stringent pressure requirement for the vacuum system. This pressure requirement is intended to minimize background radiation caused by bremsstrahlung gas-beam interactions viewed by the detector. Gas-beam intereactions produce off-energy particles which are swept into the detector by the bend magnets near the Interaction Point (IP). The average beamline pressure in the IR must be below 1 nTorr (nitrogen equivalent) [1]. This pressure requirement applies to the "mid-IR", defined in the High Energy Beam (HEB) at 2-40 meters upstream of the IP and the Low Energy Beam (LEB) at 2-30 meters upstream of the IP.

Producing sub-nTorr average pressures is especially difficult considering the copius amounts of synchrotron radiation that are deposited along the walls of both incoming beamlines. The gas load is estimated to average 10^{-7} Torr-liters/second/meter throughout the mid-IR. To achieve an average pressure of 10^{-10} Torr, distributed vacuum pumping is required on the order of 1000 liters/second/meter. This is especially difficult to accomplish without producing a high impedance which causes beam instabilities and higher-order-mode heating.

2 VACUUM SYSTEM DESIGN

The majority of Interaction Region vacuum chambers are constructed from oxygen-free copper extrusions. There are some special HEB chambers where the sychrotron radiation power is high. These chambers are constructed from stainless steel with GLIDCOP absorbers. The standard cross-section of the HEB IR chamber is shown in Figure 1. It has an octagonal beam aperture with a pumping plenum attached below the beam. The pumping plenum communicates with the beam aperture through an array of slots (Figure 2). On the backside of each set of slots is a 1 mm thick screen with 3 mm wide slots. These slots are oriented 90º to the main slots and their purpose is to block the transmission of transverse electric (TE) modes of RF power into the pumping plenum.

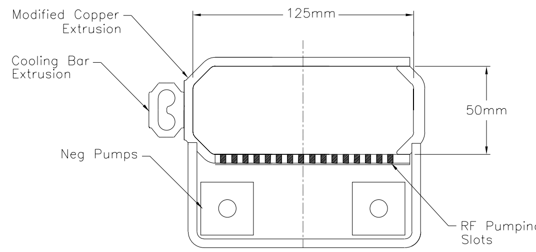

Figure 1. Cross-section of the HEB IR Chamber

The cross-section of the LEB IR chamber is shown in Figure 3. The LEB chamber has the pumping plenum adjacent to the beam aperture, but separated by a "microwave type" RF pumping screen. The pumping screen for the LEB IR chambers is shown in Figure 4.

The vacuum pump chosen for the IR is the Non-evaporable Getter (NEG). The design of the distributed NEG pumps for the PEP-II IR is an innovative departure from conventional NEG designs. SAES ST707 strip is laser cut into individual "wafers" and stacked onto a stainless steel tube with 1 mm spacers between wafers. The stainless steel tube wall serves as both the vacuum barrier and support for the NEG. A commercial tubular heater is inserted into the tube and used to activate the NEG. The heater is outside the vacuum system, so

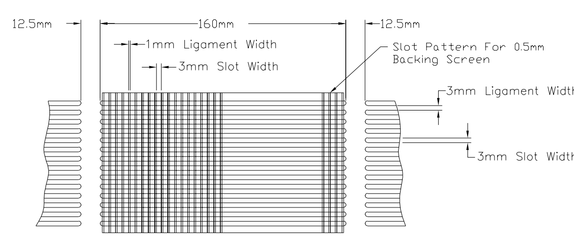

Figure 2. HEB IR pumping slots

penetration of the vacuum barrier with an electrical feedthrough is not required. With this design feature, a failed heater can be replaced with the chamber under vacuum. Each pump within the IR contains the equivalent of 18 meters of NEG strip per meter of pump length. This provides a distributed pumping speed in the range of 1000 liters/second/meter with a getter capacity of 1.8 Torr-liters CO/meter. Estimates show that with this pumping capacity, after initial beamline "clean-up" regeneration will be required only on an annual basis. The distributed NEG pumps are also supplemented by discrete ion pumps to pump hydrocarbons during machine operation and to pump hydrogen during NEG activation.

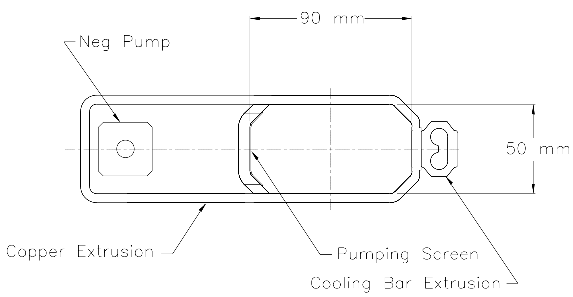

Figure 3. Cross-section of the LEB IR Chamber

3 VACUUM ANALYSIS

To produce an average beamline pressure in the 10^{-10} Torr range, it is essential to determine the locations and extent of the gasloads generated by the circulating beams. The major source of outgassing in the IR is due to photo-desorption, that is, gas expelled from the chamber walls by synchrotron radiation. Early in the PEP-II project, photo-desorption tests were conducted at Brookhaven National Laboratory. Prototype PEP-II copper vacuum chambers that had been ultrahigh vacuum processed were exposed to synchrotron radiation. Outgassing due to photo-desorption was measured to assess "clean-up" time and determine the photo-desorption outgassing coefficient (referred to as "η", with units of molecules/photon). The design value for "η" was determined in these tests and was found to be 2.0 x 10^{-6} molecules/photon after 40 Amp-hours of exposure [2].

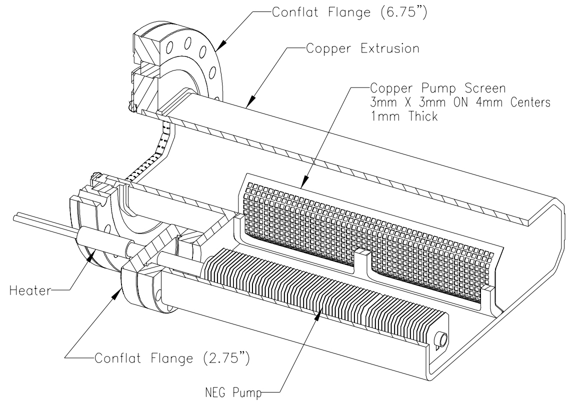

Figure 4. LEB IR pumping screen.

Both of the HEB and LEB beamlines were laid out on CADD workstations and ray traces were made of the synchrotron radiation "fans" generated by the bend magnets. From the ray traces, profiles of the synchrotron radiation power incident on the walls of the chambers were calculated. Distributed gas loads were calculated by converting the synchrotron radiation power profiles to gas load profiles (in nitrogen equivalent) using the empirical photo-desorption data.

Pumping speed and sorption capacity for SAES ST707 NEG material is well known. Manufacturer's data for carbon monoxide pumping speed was extrapolated for the actual surface area of the NEG material in the IR pumps. Prototype pumps were built and tested to verify the design calculations. The results of these tests are reported in reference [3].

It is one thing to design a high speed UHV pump, it is quite another to deliver high "net" pumping speed to the beam aperture where it is required. The design of the high conductance/low impedance RF pumping screens were the most challenging aspect of the project. Several iterations were made between the vacuum engineer and the electromagnetic physicist to come up with a compromise design that satisfied all of the design criteria.

Calculating the molecular conductances of the RF pumping screens was done analytically. As a check, a two-dimensional Monte Carlo model was made of the screens [4]. The model was compared to a benchmark model of the PEP-II High Energy Ring arc screen design which had been protoyped and measured. The calculated molecular conductance of the HEB IR pumping slots is

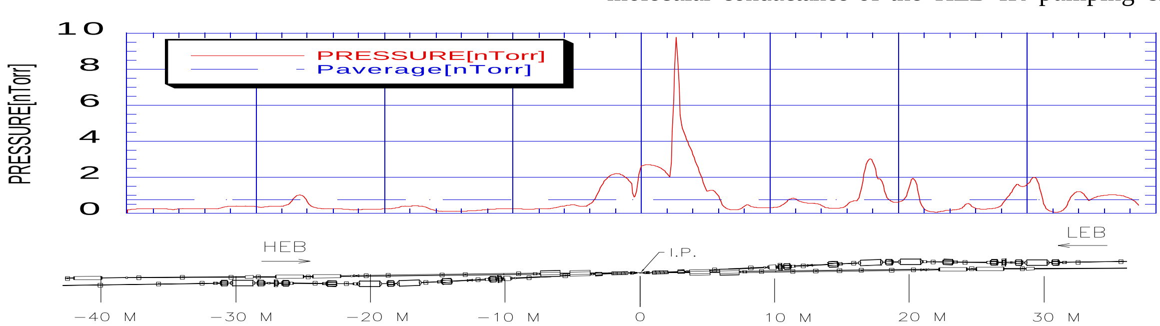

Figure 5. Interaction Region Plan and Pressure Profile

2000 liters/second/meter (nitrogen equivalent). The calculated molecular conductance of the LEB IR pumping screen is 1600 liters/second/meter.

With the gasloads and the net pumping speeds calculated, the next step was to generate a one-dimensional beamline pressure profile. This was done with the use of pressure pipeline code developed for vacuum beamlines [5]. Each discrete section of beamline was characterized by its length, axial conductance, gasload, and pumping speed. Once the beamline model was built, it was straightforward to make changes to address localized pressure problems. The final pressure profile for the upstream sections of the HEB and LEB are shown in Figure 5. There is a sharp pressure peak the IP due to low beamline conductance and the absence of pumping. This pressure peak is not expected to produce significant background radiation. The average beamline pressure in the HEB mid-IR is 0.75 nTorr. The average beamline pressure in the LEB mid-IR is 1 nTorr after 40 Amp-hours of machine operation.

4 IMPEDANCE ANALYSIS

From a beam impedance point of view, long slots are preferred over holes, since the main contribution to the impedance comes from the ends of the slots. However, long slots allow TE power to penetrate into the pumping plenum which can cause excessive heating to the NEG pump. The ideal situation is to place a screen with small holes at the back of the slots to block TE power penetration. In this manner, the hidden holes produce only a small impedance. However, here in the IR, vacuum conductance considerations required the RF screen to be placed directly at the beam chamber wall increasing the impedance substantially. In this case an optimized design had to accomodate both beam impedance and vacuum conductance requirements.

The HEB IR pumping slots (Figure 2) contribute an inductance of 0.15 nH, which is small compared with the overall High Energy Ring impedance budget of 50 nH. The IR upstream high energy beam dump chambers have about 76,000 holes (3 mm square) located at the bottom of the beam chamber. They contribute an inductance of 3.41 nH, which is still a relatively small fraction (7%) of the impedance budget. The LEB IR pumping screen (Figure 3) creates an inductance of 1.2 nH, which is also relatively minor. Hence, the two pumping screen designs for the HEB IR and the LEB IR will have a small effect on the beam impedance.

The effectiveness of both the long slots and the "microwave screen" designs in shielding the TE power is evaluated by transmission calculations of a TE_{10} mode propagating in the beam chamber. The results are shown in Figure 6. The deviation of the transmission coefficient from unity represents radiation penetrating through the screen. The HEB slots allow negligible penetration over a broad range of frequencies. The slots are long enough to interrupt the azimuthal current of the TE mode. In contrast, the screen design is opaque to TE penetration at all frquencies with 100% transmission down the beam aperture.

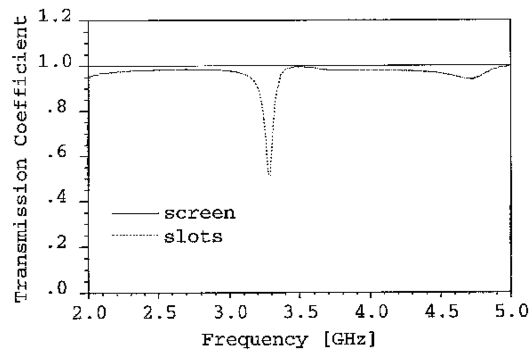

Figure 6. TE Mode Transmission Spectrum for pumping slots and screen.

5 SUMMARY

The design and analysis of the vacuum system for PEP-II Interaction Region has been described. The IR vacuum system performance has been shown to produce average beamline pressures at or below 1 nTorr. The pumping screens have been shown to be minor contributors to the overall machine impedance budgets and to protect the NEG pumps from TE radiation.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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