PRESSURE DISTRIBUTION FOR DIAMOND STORAGE RING

O.B. Malyshev, E. Al-Dmour, J.D. Herbert and R.J. Reid, ASTeC, Daresbury Laboratory, UK

Abstract

diamond is the United Kingdom's 3rd generation light source project, which is currently moving from the design phase into the procurement and construction phase. It is due to come into operation with beam for users in 2006.

diamond will be based on a 3 GeV electron storage ring of 561.6m circumference with a stored beam current of 300mA. As is the case for most such machines, the vacuum specification has been set at an operational pressure of 10^{-9} mbar to give a beam lifetime of 10 hours at the design current. The storage ring vacuum system will be based on conventional technology and the majority of the vacuum vessels will be constructed of stainless steel. The storage ring – with the exception of the insertion device vacuum chambers - has not been designed to be bakeable *in situ*, but all components will be baked as sub assemblies prior to installation.

This paper will describe a novel method of calculating pressure distributions in such large, conductance limited vacuum systems using the commercially available mathematical package Mathcad 2001. Such calculations demonstrate that the design pressure will be achieved after 100 Ah of beam conditioning using the pumping scheme, which will be described.

1 INTRODUCTION

The diamond Storage Ring [1] is divided into 24 cells. each comprising a "straight" and an "arc". Most straights will accommodate an insertion device (ID), although some will be devoted to machine requirements. Each straight will have an in-line vacuum isolation valve at either end. The arc contains the double bend achromat, short pieces of straight pipe at each end and the spouts to the beam line front ends. There are no in-line vacuum valves in the arcs. Figure 1 shows the arc layout in schematic form.

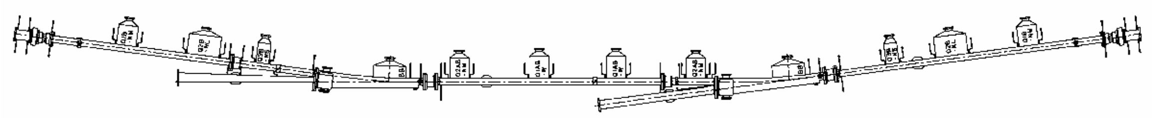

Figure 1: Schematic of arc layout.

2 UHV PUMPING PHILOSOPHY

The design aims to obtain the necessary pumping using only lumped pumps, thereby simplifying mechanical design and serviceability since no special arrangements are required to accommodate pumps inside the electron beam vacuum envelope.

Most pumps will be attached to the beam tube by spouts coming in between the poles of the dipole and quadrupole magnets. Gas flow conductance of the spouts limits the available pumping speed. Some pumps can be fitted beneath the crotch absorbers or beam port absorbers, presenting a larger pumping speed. Pumping ports will be screened from the beam by a thin mesh, which has little effect on the available pumping speed.

Standard UHV pumps will be used: differential diode sputter ion pumps, titanium sublimation pumps (TSP), and cartridge non-evaporable getter (NEG) pumps.

The relatively new technology of vessels internally coated with a film of sputtered NEG material [2] will be adopted in special situations. Although this provides good pumping speed in conductance limited situations, it is a new technology and long-term efficacy is still not proven. It will be adopted only for vessels which can readily be replaced without compromising the overall operation of the storage ring, e.g. narrow gap insertion device (ID) vessels.

3 AVERAGE DYNAMIC PRESSURE

3.1 General considerations

The reduction of pressure in an electron storage ring exposed to synchrotron radiation is well known [3]. Beam cleaning is reasonably well understood and pragmatic predictions of clean up rates can be made based on the experience of operating storage rings. The basic science underlying the complex process is not well understood. Neither thermal nor photon stimulated desorption yields are constant or well defined, varying between materials, with preparation techniques and with the previous history of irradiated samples. Actual and predicted values of gas desorption loads may differ by factors of two or more because of these uncertainties, so that even with a very good model and precise methods, calculated pressures can only be accurate to this level.

3.2 Model

The equations of gas dynamic balance inside a vacuum chamber can be written as:

$$V\frac{dn}{dt} = q - cn + u\frac{d^2n}{dz^2}; \quad (1)$$

where n is the gas volume density; z is the longitudinal axis of the vacuum chamber; V is its volume; q is the gas desorption flux; c is the distributed pumping speed, u is the specific vacuum chamber molecular gas flow conductance per unit axial length. Gas desorption consists of two main sources: thermal and photon stimulated desorption: $q = \eta_t F + \eta_\gamma \Gamma$; where η_t is the thermal desorption yield, F is the vacuum chamber surface area, η_γ is the photon stimulated desorption yield, Γ is the synchrotron radiation photon flux.

3.3 Input parameters

Photon flux.

In the current design of diamond, ~30% of the dipole synchrotron radiation irradiates vessel walls, ~45% the crotch absorber and ~25% goes down the beamlines. That from insertion devices all passes along the beamline.

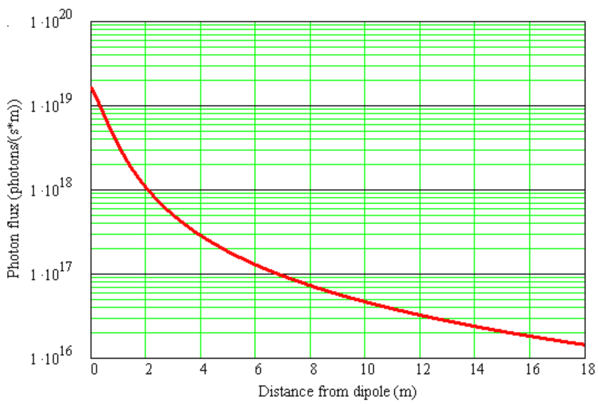

Figure 2: Photon flux incident on the vacuum chamber walls as a function of distance downstream from a dipole.

The total photon flux from the dipoles is given by:

$$\Gamma_{tot}\left[\frac{\text{photons}}{\text{sec}}\right] = 8\cdot 10^{20}\cdot E[\text{GeV}]\cdot I[\text{A}] \qquad (2)$$

The incident photon flux per meter of vacuum chamber depends on the total photon flux and the distance from the source point to the point of impact, z, and is given by:

$$\Gamma(z) = \frac{\Gamma_{tot}}{2\pi}\left[\frac{(R+a)}{(R+a)^2+z^2} - \frac{Rz}{\left((R+a)^2+z^2\right)\sqrt{z^2+2Ra+a^2}}\right], \qquad (3)$$

where R is the dipole bending radius and a is horizontal half aperture of the vacuum chamber. For diamond the flux, shown in Figure 2, varies from $1.5\cdot 10^{19}$ to $1.5\cdot 10^{17}$ photon/sec/m between the end of the dipole and 5 m downstream. The photon flux along the insertion device straights will be lower: $1\cdot 10^{17}$ to $2\cdot 10^{16}$ photon/sec/m.

Thermal desorption.

Thermal desorption from surfaces determines the base pressure in the storage ring. Outgassing rates $<10^{-11}$ mbar·l/sec/cm^2 can be obtained with well-prepared materials after a few hundred hours of pumping in systems prebaked before installation in the storage ring.

Photodesorption (PSD).

With beam, the main gas source is photon stimulated desorption, whose yield, η, decreases with photon dose as D^{-a} [4–10]. At room temperature, a is between $2/3 \leq a \leq 1$. Proper cleaning procedures, pre-baking and baking *in-situ* all reduce the *dose* required to obtain a given value for η. The initial desorption yield of a pre-baked or *in-situ* baked vacuum chamber will be lower than that from an unbaked vacuum chamber, but the cleaning rate (the exponent a in D^{-a}) is also lower. Similarly the PSD yields reach the same low value of η and of clean-up rate but at higher photon doses in the unbaked case. At very high photon doses, there is no significant difference between the different cases (Figure 3).

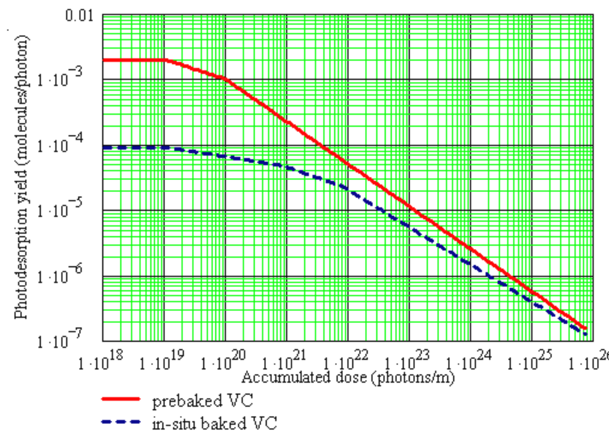

Figure 3: PSD yield for CO for prebaked and *in-situ* baked vacuum chambers. (Yields for doses higher then 10^{23} photons/m are extrapolations.)

Foerster *et al* [4] and Herbeaux *et al* [5] have measured desorption from stainless steel vacuum chambers pre-baked at 200°C for 24 hrs (but not baked *in-situ*) by synchrotron radiation with E_c=3.35 keV and 500 eV respectively for doses up to $2\cdot 10^{23}$ photons/(s·m), equal to 1.7 A·h operation in diamond. To calculate pressures in diamond at 100 A·h, extrapolation must be made to a dose of $1.2\cdot 10^{25}$ photons/(s·m). Herbeaux [5] finds a=1 and Foerster [4] a=2/3. Extrapolating Foerster's data gives the more pessimistic pressure and conditioning time for diamond. Figure 4 shows the calculated desorption yields and desorption fluxes as a function of distance from the dipole for different machine conditioning times.

OFHC copper has about the same PSD yield as stainless steel after a dose of about 10^{23} photons/(s·m) [6–8], so using copper inside the vacuum chambers should not affect the predicted pressure significantly. Anashin *et al* [10] describe PSD measurements at E_c=2.66 keV from a copper crotch absorber and these are used for the estimates of PSD from diamond crotch absorbers.

3.4 Pressure profiles after 100 Ah conditioning.

Pressure profiles along the arcs were calculated using Mathcad 2001 [11]. Calculations were made for thermal desorption and photon stimulated desorption using a suite of pumps comprising 12 240 l/sec and 2 500 l/sec ion pumps, 2 180 l/sec NEG pumps and 2 1000 l/sec TSPs per arc (Figure 5). Summing the two gives the dynamic pressure profile at a given beam current.

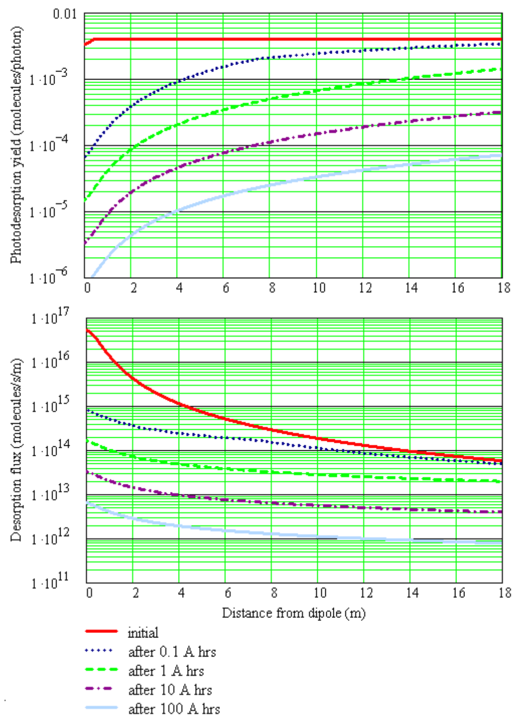

Figure 4: Photodesrption yield and desorption flux for a straight irradiated by SR from dipole as s function of distance from the dipole and of beam dose.

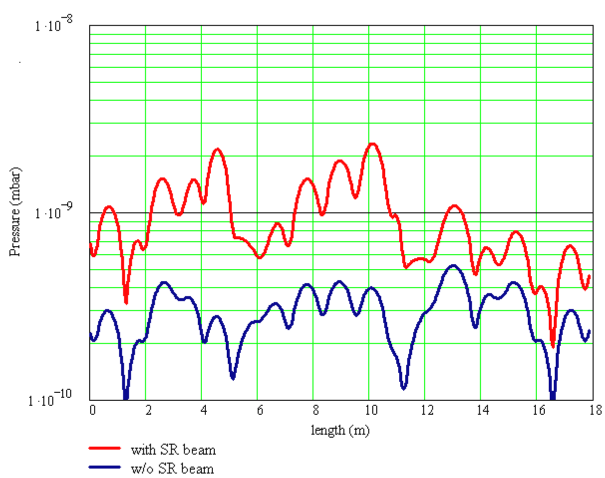

Figure 5: Pressure profile along the arc.

Monte-Carlo simulations.

The applicability of what is basically a one-dimensional simulation to a 3-dimensional problem may arise. Much of the storage ring is a close approximation to a thin pipe, so is quasi one-dimensional. The analytical result has been benchmarked against a commonly used Monte-Carlo simulation program [12]. Calculations were carried out for an elliptical cross section vacuum chamber and for the most complicated element of the diamond vacuum chamber, the dipole vessel. There is no significant difference in the results for the elliptical vacuum chamber, but there are some minor differences in the pressure profiles for the dipole chamber. However, the *average* value of pressure along this vessel is in fact similar in each case. Therefore, it is concluded that overall estimates of pressure profiles and of average pressure along the diamond arc can be made to sufficient accuracy using the analytical method. This is much faster, more convenient and more flexible for calculations where many variations in input parameters are required.

Average pressure along ID straights after 100 Amp·hrs conditioning with SR from dipoles.

Two different types of ID straight vacuum chambers, of lengths 5.5 and 8.5 m in each case, have been considered. The first is a simple make-up pipe of diameter 100 mm. 5.5 m long pipes with three 240 l/sec ion pumps (one at each end and one in the middle) reach an average pressure of $8.6\cdot10^{-10}$ mbar. Similar 8.5 m long pipes need four of these pumps equally spaced to reach an average pressure of $9.5\cdot10^{-10}$ mbar. Initially, such vessels will be installed in most ID straights in diamond.

The second type of chamber is an elliptical pipe 7 to 12 mm high and 80 mm wide with the inside surface NEG coated. The narrow gap severely limits the longitudinal vacuum conductance. Again, lengths are 5.5 and 8.5 m. In each case, only one 240 l/sec ion pumps pump at each end is required to give average pressures of $2.0\cdot10^{-10}$ mbar and $4.7\cdot10^{-10}$ mbar respectively.

4 CONCLUSIONS

An operational pressure in the machine of 10^{-9} mbar giving a minimum beam lifetime of 10 hours is feasible after a conditioning time of about 100 Ah under the assumptions made. The machine does not require *in-situ* baking, but all sub assemblies require prebaking under UHV conditions. NEG coated vacuum chamber will be used for narrow-gap ID vacuum chambers.

5 REFERENCES

[1] V P Suller, this Conference, paper 936 - TUPLE002.
[2] C. Benvenuti *et al*, Vacuum **53** (1999) 219.
[3] R J Reid, Vacuum **44** (1993) 473.
[4] C.L. Foerster *et al.*, J.Vac.Sci.Technol A8(3), May/June 1990, pp.2856–2859.
[5] C. Herbeaux *et al.*, J.Vac.Sci.Technol A17(2), Mar/Apr 1999, pp.635–643.
[6] V.V. Anashin and O.B. Malyshev. Novosibirsk, 1995, unpublished results.
[7] O. Gröbner *et al.*, J.Vac.Sci.Technol A12(3), May/Jun 1994, pp.846–853.
[8] Y. Hory *et al.*, J.Vac.Sci.Technol A12(4), Lul/Aug 1994, pp.1644–1647.
[9] C.L. Foerster *et al.*, J.Vac.Sci.Technol A12(4), Jul/Aug 1994, pp.1673–1677.
[10] V. Anashin *et al.*, Proc. EPAC-98, Stockholm, 22–26 June, 1998, v. 3, pp. 2163–2165.
[11] Mathsoft, Inc., Cambridge, Ma., USA.
[12] “Molflow”, courtesy of R. Kersevan, Elettra.