CALCULATION, MEASUREMENT AND ANALYSIS OF VACUUM PRESSURE DATA AND RELATED BREMSSTRAHLUNG LEVELS ON STRAIGHT SECTIONS OF THE ESRF

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Abstract

One of the major personal safety issues of modern synchrotron radiation (SR) light sources is the minimization of the exposure of beamline staff and users to high-energy bremsstrahlung (BS) radiation generated in the straight sections of the storage ring and entering the optics hutches of the beamlines. This is particularly important when insertion device (ID) narrow-gap chambers are installed, nowadays characterized by very low specific conductances. At the ESRF, this has led to the implementation of systematic measurements of BS levels and vacuum conditioning curves, in conjunction with the installation of non-evaporable getter (NEG)-coated ID chambers. A dedicated beamline is used to do on-axis measurements of the BS intensity during the initial conditioning period of newly installed NEG-coated ID chambers. This paper shows results of measurements and calculations performed throughout the years, and comments on the suitability from the radiation safety point of view of the installation of NEG-coated chambers in large numbers around the ring.

VACUUM SIMULATIONS AND MEASUREMENTS

One of the first things to do in order to understand the impact of different pumping and outgassing configurations on the BS levels measured on axis, is to make up a realistic three-dimensional (3D) model of the vacuum system. This has been done using the montecarlo (MC) code Molflow [1]. The vacuum system between dipole 2 of cell 5 and crotch 1 of cell 6 has been modeled, for a total length of 20.6 m. Of this, about 15 m are on the straight line-of-sight of the ID6 beamline (BL), where 5.8 m are taken by the narrow-gap ID chamber and the two pumping manifolds at the upstream (UPS) and downstream (DWS) ends, as explained in a companion paper [2]. Several MC calculations have been run, in order to simulate the various cases possible [2], e.g. the installation of a new NEG-coated chamber on two previously conditioned UPS/DWS chambers. Under molecular flow regime, i.e. when molecules move independently from each other and collide only with the walls of the vacuum system, separate MC simulations can be run for different outgassing sources, and the pressure curves thus obtained can then be combined linearly in such a way that the pressures, calculated at the gauge locations, match the measured pressures. The SR-induced outgasssing rate of each absorber along the vacuum chambers have been calculated in advance, and

properly scaled in order to consider the vastly different linear photon flux densities: for example, a crotch 1 absorber gets of the order of 2000 times more photons per unit length as compared to a CV4 absorber (see the cell schematics at the bottom of figure 1). The same power-law curve $\eta = \eta_0 \cdot D^{-\alpha}$, where η is in molecules/photon and D in photons/m, and an exponent of $\alpha = -2/3$ has been assumed [3] for all absorbers. Such a value for α is consistent with many vacuum conditioning curves that have been measured at the ESRF, on the machine and on a dedicated photo-desorption beamline. As a first check that the MC model and the physical assumptions described above were correct, several benchmark calculations have been run by using data taken some time ago during machine dedicated time (MDT) runs, using calibrated leaks [4]. Figure 1 shows the calculated pressure curves for the case when a 4.4E-7 atm·cc/sec argon leak and a 6.2 atm·cc/sec methane leak were separately connected at the UPS pumping manifold (in front of the PEN3 gauge), and let into the chamber under static conditions (i.e. no beam stored). It also shows the pressure profiles calculated for a unitary outgassing rate uniformly given off by the walls of the system (e.g.. to simulate thermal outgassing), and the cases when all absorbers other than the UPS and ID chamber (indicated as "ALU/NEG" on the figure) are the source of gas. All pumping speeds of sputter-ion pumps (SIPs) and NEG pumps (GPs) have been carefully estimated by calculating separately the reductions caused by the geometry of the pumping ports [5].
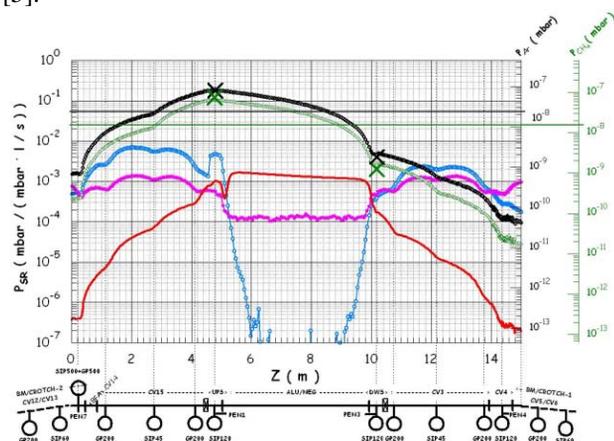

Figure 1: MC calculation of the pressure profiles for Ar (black), CH_4 (green), scales on the right. Thermal (magenta), and SR-induced gas loads (red and blue, for UPS/ID chambers only, and all other absorbers, respectively), scale on the left.

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The NEG coating along the 5 m-long ID chamber has been assumed to have a residual sticking coefficient of 0.01, as all measurements have occured after rather large integrated beam doses, when the coating had lost most of its pumping action (see for instance ref.10 in [2]).

Two big "X"s in black and green indicate the *measured* pressures (shown on the two scales on the right, separately for the two leaked gases argon and methane). It can be seen that the calculations are in very good agreement with the measurements. This gives us confidence that the geometrical 3D model made for the MC vacuum analysis is correct. An important point to stress here is that the 3 curves for thermal, SR desorption from UPS/ID only, and SR dsorption from the remaining absorbers, must then be combined with different weights, corresponding to the conditioning level of the respective sections [2].

Figure 2 shows a screen shot of the MC program while the 7 structures modeling the complete dipole2-to-crotch1 vacuum system was running.
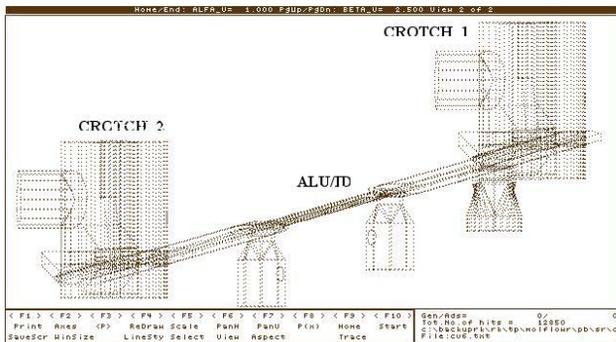

Figure 2: Molflow screen shot.

These and other MC vacuum calculations have been used as input for BS calculations, which in turn have been compared to radiation dose measurements, as described in the following section.

GAS-BREMSSTRAHLUNG MEASUREMENTS

ESRF Radiation Protection Policy

The ESRF radiation protection policy stipulates that the annual dose limit of 1 mSv for non-exposed workers must be respected in all areas, accessible during operation. The annual limit of 1 mSv corresponds to a derived dose rate limit of 0.5 μSv.h^{-1}, assuming 2000 working hours per year. Taking into account the fact that people, such as users, will stay only at the ESRF for a limited period of time, ESRF has decided to use a more stringent dose constraint, by permanently limiting the integrated dose over 4-hours periods:

$$\int_{4\,hours} \dot{H} \cdot dt < 4 \times 0.5 = 2 \ \mu Sv \qquad (1)$$

Gas-bremsstrahlung measurements

Scattered bremsstrahlung photons and bremsstrahlung induced neutrons largely define the shielding requirements of the optics enclosures of insertion device (ID) beamlines at the ESRF. Gas-bremsstrahlung, generated by the interaction between the electrons and residual gas molecules in the corresponding straight section of the storage ring, is the dominant source of these high energy photons. The power P of the gas-bremsstrahlung can be written as:

$$P = C \times \frac{dE}{dx}(E_e) \times p \times I \times L, \qquad (2)$$

with $\frac{dE}{dx}(E_e)$ the electron stopping power for the residual gas, p the average pressure in the straight section, I the stored beam current, L the length of the straight section (from dipole to dipole) and C a proportionality factor. Since the pressure p will be proportional to the stored beam current I, one sees from expression (2) that the overall gas-bremsstrahlung power will be proportional to the square of the stored beam current I.

ESRF is at present more sensitive to the problem of gas-bremsstrahlung than most other 3rd generation synchrotron radiation facilities due to its combination of high energy (6 GeV), long straight sections (15 m), high stored beam current (200 mA) and small gap ID vacuum vessels ("10 mm" version, internal height 8 mm). A lot of effort is therefore made to characterise new ID vacuum vessels in terms of gas-bremsstrahlung production. To do so, each new ID vessel is initially installed on a dedicated straight section in the storage ring, corresponding to the machine diagnostics / safety beamline. Inside the optics hutch of this beamline, a simple experimental set-up allows the on-axis measurement of the gas-bremsstrahlung levels during the initial conditioning of the vacuum vessel. These measurements are made with a small 0.6 cm^3 thimble ionisation chamber, covered with 3 mm of lead to stop the synchrotron radiation from the upstream and downstream dipole. The optics hutch of this special beamline has shield walls of 5 cm of lead and 10 cm of polyethylene, substantially thicker than the standard ESRF optics hutches. This allows the operation of this beamline, despite the initially poor vacuum conditions in the corresponding straight section.

Figure 3 shows the normalised on-axis bremsstrahlung measured during the initial vacuum conditioning of three 5 meter long, 8 mm vertical aperture, NEG-coated aluminium ID vessels, installed on the ESRF storage ring. The measured bremsstrahlung, normalised to the square of the stored beam, is shown as a function of the integrated electron dose. One sees that after an integrated dose of 100 A·h the radiation levels have decreased by roughly two orders of magnitude. Note that 100 A·h corresponds to 23 days of constant operation at the nominal average current of 185 mA.
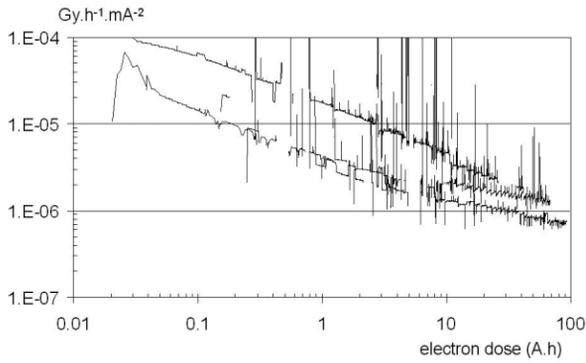
Figure 3: Gas-bremsstrahlung measurements during initial vacuum conditioning of three 5 m long, 8 mm vertical aperture, NEG-coated aluminium ID vessels installed on the ESRF storage ring.

Installing the new ID vessels on this dedicated straight section has a double advantage. First of all, it allows to detect possible problems with an individual NEG coated vessel, before this would be installed on another straight section, eventually blocking the corresponding beamline because of radiation levels outside the optics hutch, incompatible with the dose constraint given by expression (1). Secondly, it allows the conditioning of the vacuum vessel (and the corresponding upstream and downstream vacuum vessels), again, without blocking a user beamline.
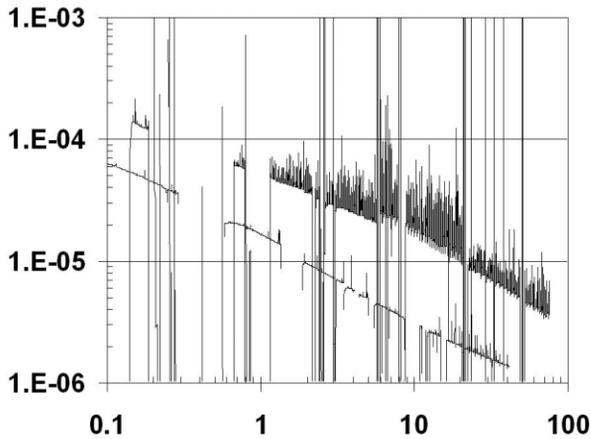

Figure 4: Gas-bremsstrahlung measurements during initial vacuum conditioning of normal (lower curve) and a problematic (upper curve) 5 m long, 8 mm vertical aperture, NEG-coated aluminium ID vessels installed on the ESRF storage ring. Scale units as per figure 3.

Indeed, after the pre-conditioning during a whole experimental run, the reconditioning during the few days of machine restart after the shutdown, are generally sufficient to allow the operation of the corresponding beamline from the first day onwards of user mode. An example of the bremsstrahlung measurements for a NEG coated vacuum vessel that did show problems is shown in figure 4.

The measurements were characterised by a higher average dose level, compared to a normal vessel, and by the presence of frequent radiation spikes.

Other on-axis measurements using TLDs inside a PMMA phantom have been done. The results of these measurements are in good agreement with results of Monte-Carlo calculations, using the vacuum profiles described above [5].

ACKNOWLEDGEMENTS

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