Conception of vacuum system for SRS SKIF

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Introduction

Low emittance design of magneto-optics system of modern SRS significantly limits available aperture for beam pipe. Therefore distribution pump based on non-evaporated getter (NEG) coating, first time applied in ESRF insertion devices, starts to be very popular. For example, most pats of vacuum beam pipes of SRS MAX4 and SIRIUS are NEG coated. In practices such a system does not need any conditioning excepting the NEG activation. It means the required dynamic ultra-high vacuum can be achieved right after the NEG activation. But the activation itself is a heating procedure at 160 ÷ 200C^o, which needs opening of magnets (MAX4 solution) or a space for installation of heaters & thermal insulators (SIRIUS solution) and many mechanical compensators with RF contacts. On other hand, the developing in recent years of very compact combined vacuum pumps, based on NEG cartridges and sputter ion-getter pumps, gives opportunity to return to classic system with lumped pumps but placed at short distance: about one meter or even less.

The vacuum system of SRS SKIF storage ring will contain both NEG coating and lumped combined pumps. NEG coating will be used in long and narrow aperture insertion devices operated at room temperature. The lumped pumps will be applied in arcs where connection of many compact combined pumps is possible. Obvious advantages such a solution are: the system is unbaked (minimum quantity of mechanical compensators required), less sensitive to micro-leaks, low wall impedance. The paper describes a general approach for determination of main parameters and conditioning duration of SKIF storage ring vacuum system with lumped pumps in arcs.

“Vacuum” lifetime

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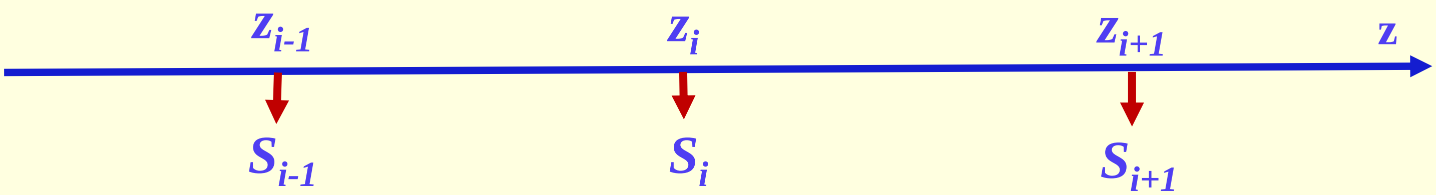
Mainly an interaction with CO molecules defines the “vacuum” lifetime of 3 GeV electrons. The table presents general interaction processes and corresponding lifetimes at CO pressure level 1 nTorr .

Process	Lifetime [h]
Elastic (Rutherford)	43
Inelastic (bremsstrahlung)	66
Total	**26**

To reach “vacuum” lifetime 10 hours, dynamic pressure level of CO must be not more 2.5 nTorr or 3.3E-7 Pa

Average dynamic pressure in system with lumped pumps

One-dimension approach and application of Knudsen diffusion model is very useful for calculation average dynamic pressure in a storage ring especially at early stage of a project when exact placement of the vacuum pumps is not defined yet.



One-dimension model

Assuming a size of a pump connection much less than average distance between pumps, one can apply Knudsen mass-balance differential equitation with the use δ-function for calculation of dynamic pressure profile in one-dimension complex vacuum system:

$$A(z)\frac{\partial P(z)}{\partial t} = q(z) + \frac{\partial\left(u(z)\frac{\partial P(z)}{\partial z}\right)}{\partial z} - \sum_{i}^{N} S_i \delta(z - z_i) P(z) \approx 0$$

where *A[m²]* – cross-section area of the vacuum beam pipe, *q[Pa*m²/s]* – flux of desorbed molecules per unite length, *u[m⁴/s]* – molecular conductivity of the beam pipe for unite length, *P[Pa]* – queasy-dynamic pressure level, S_i [m^3/s]– pumping speed of pump number *i* connected to beam pipe at coordinate z_i , *N* – number of pumps.

Simplified system

Trivial solution can be found for simplified system with *A(z)*, *u(z)*, *q(z)* constant and equidistant placement of the pumps with the same pumping speed. In this case an average pressure can be found from:

$$\hat{P} = \frac{qL^2}{12u} + qLS = \frac{qL^2}{12u(1-k)}$$

where *L* – distance between pumps, $k = P_s/\hat{P}$ is an efficiency of the lumped pump application. *Ps* – is the pressure at the pump entrance. Usually the *k* varies in range 0.2…0.3.

It is interesting to note that variation of distance in the range 0.5L to 1.5L, keeping L in average (total number of pumps is constant), causes the average pressure variation just in the range 1…1.6 of its value at equidistant placement. So, the effectiveness of the pump placement can be describe by corresponding coefficient g:

$$\hat{P} = g\frac{qL^2}{12u(1-k)}$$

where $A[m^2]$ – cross-section area of the vacuum beam pipe, $u[m^4/s]$ – molecular conductivity of the beam pipe for unite length, $q[Pa*m^2/s]$ – flux of desorbed molecules per unite length, $P[Pa]$ – queasy-dynamic pressure level, S_i [m^3/s]– pumping speed of pump number *i* connected to beam pipe at coordinate z_i , *N* – number of pumps.

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Desorption rate

Due to very high photon flux (in average about 2E18 ph/m/s for SKIF at I=0.4A), the photon-stimulated desorption is much higher in compare with thermal desorption rate even after long time treatment by photons. The photon-stimulated desorption and its time evolution due to surface treatment (conditioning) be photons are:

$$q = \sigma\dot{\gamma}/K \qquad \sigma = \sigma_0/(1+(\gamma/\gamma_{1/2})^{\varepsilon})$$

Where σ [molecule/ph] – photo-desorption coefficient, $\dot{\gamma}$ [ph/s/m] - photon flux, K [molecule/Pa/m^3] = 2.4E20, σ_0 - initial desorption coefficient 0.001… 0.01 for CO, γ – photon dose per meter, $\gamma_{1/2}$ ~ 1E19 – photon dose than desorption rate decreases by a factor of two, ε = 0.67…1 – a power factor of photo-desorption decreasing with photon dose accumulation.

Parameters for calculation

Parameter	
Electro energy, E [GeV]	3
Electron current, E [A]	0.4
Average photon flux [ph/s/m]	2E18
Inner diameter of the vacuum beam pipe	0,027
G - factor	1.6
K - factor	0.25
Limmitation C=P*I (during conditioning) [Pa*A]	2.6E-7

Conditioning duration

Taking into account a limitation P*I ≤ 2.66E-7 [Pa*A], the conditioning duration can be estimated from equation:

$$t \approx \frac{\gamma_{1/2}}{5 \cdot 10^{18}} \cdot \frac{2 \cdot I^{\frac{2-\varepsilon}{\varepsilon}}}{2-\varepsilon} \left[\frac{\sigma_0 g L^2 E}{3.6 L_p u C (1-k)} \right]^{1/\varepsilon}$$

In the worst case the conditioning time is about 3 months

It is interesting to note, that at ε=2/3, the time ~ $L^3/d^{4.5}$ (u~d^3).

General performance of the vacuum system of SKIF storage ring

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Tasks:

1. “Vacuum” lifetime: > 10h (dynamic pressure of CO $< 2.5\cdot10^{-9}$ Torr)

2. Absorption of 200 kW SR radiation

3. Low impedance design

Design conception contains best solutions applied in “accelerator world”:

Main material: aluminum alloys – any profiles are available and cheap, simple machining, high electrical conductivity, well weldability, all types of connection between components are developed (LEP, PEPII, SuperKEKB,…).

Components: connections - SuperKEKB type, compensators – PEPII type (with controlled force on sliding contact), BPMs – MAX4/SIRIUS/DIAMOND

Pumping system:

- **straight sections**: cryo-pump or distributed NEG (coating) – best solution for narrow-aperture chambers.

- **arcs**: Lumped compact combined pumps placed at distance about 1m in average (Spring8-II, ESRF (partially)). Expected conditioning time 3 ÷ 6 months. Advantages in compare with NEG coating variant: the system is unbaked (minimum quantity of bellows required), less sensitive to micro-leaks, low wall impedance.