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ELECTRON-CLOUDLESS OPERATION MODE OF THE NICA COLLIDER

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The effect of electron clouds in NICA collider was analyzed first in 2008 at development of NICA CDR [1]. The simulation results were revised, and renewed numbers are presented in this report. Both simulations were performed with ECLOUD code, version 3.3 [2].

Впервые эффект электронных облаков (ЭЭО) для коллайдера NICA был проанализирован в 2008 г. [1]. Представляются новые результаты, вошедшие в новую версию концептуального проекта ускорительного комплекса NICA. Обсуждаются режимы «безоблачной» работы коллайдера NICA [2]. Моделирование проводилось с использованием пакета программ ECLOUD, версия 3.3 [2].

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INTRODUCTION

Usually by electron cloud (e-cloud) effect one means the so-called «beam induced multipacting» — buildup of secondary electron avalanche («electron cloud») in the electric field of particle bunches circulating in a cyclic accelerator (collider) [2]. This effect leads to significant deterioration of vacuum in the accelerator and, as a consequence, fast circulating beam particles loss. One should note that the multipacting phenomenon is well known in RF and microwave electronics, where such an electron avalanche (discharge) is provoked by high-frequency electric field.

The criteria for e-cloud formation can be formulated in the following way [2, 3]. The necessary (or «resonance») condition is

$$N_{b,\mathrm{neces}} > \frac{\beta^2 R^2}{Z r_e S_b}, \quad S_b = \frac{C}{q}, \tag{1}$$

here N_b is the ion number per bunch; βc is the ion velocity; R is the radius of vacuum chamber; Z is the ion charge; r_e is the electron classic radius, i.e., interbunch distance; C is the ring circumference, and q is the bunch number.

The sufficient condition (acceleration of secondary electron in the bunch electric field up to «critical» energy) is the following:

$$N_{b,\mathrm{suf}} > \frac{\beta R}{Z r_e}\sqrt{\frac{E_c}{2 m_e c^2}}. \tag{2}$$

Here the critical energy E_c is the secondary electron energy sufficient for kicking out of the chamber wall more than one electron.

1. SECONDARY ELECTRON EMISSION

Another effect of e-cloud buildup can be the storage of secondary electrons in ion bunch resulting in neutralizing the bunch space charge and changing the betatron tune shift [4]. This effect, as estimates show, is more or less insignificant and we do now consider it here.

Secondary electron emission, as we see from consideration above, is very critical phenomenon for e-clouds development, and the value of Secondary Electron Yield (SEY) is a critical parameter. Spectrum of secondary electrons — SEY dependence on energy — is very sensitive both to material of vacuum chamber wall and to its conditioning. SEY data are available for pure metals (Fig. 1, a). The similar data for «technical surfaces» representative for vacuum chambers are quoted in [2]. One can see that the SEY values for «technical» copper (Cu) and stainless steel (St) (Fig. 1, b) are slightly larger than for pure metals (Fig. 1, a).

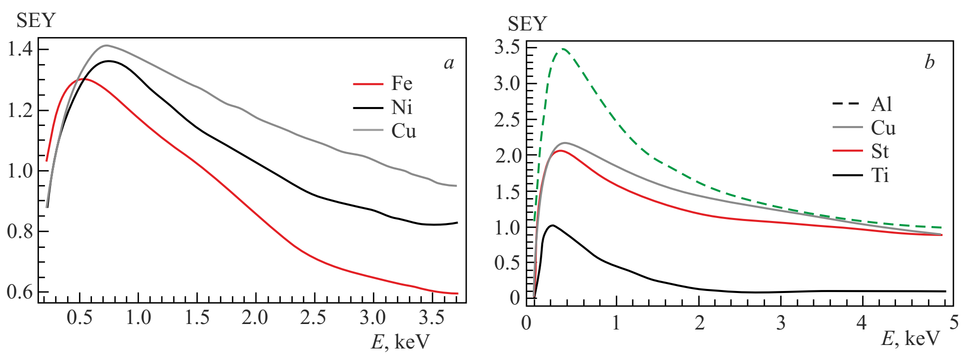

Fig. 1. Color online. a) Secondary electron yield vs. primary electron energy for different materials: Fe, Ni, Cu [5]. b) Secondary electron yield vs. primary electron energy for perpendicular incidence and for technical surfaces representative for vacuum chambers [2]; materials: titanium (Ti), stainless steel (St), copper (Cu) and aluminum oxide Al_2O_3 (Al)

All these data are basic information for the estimates of e-cloud effect development.

Substituting into criteria (1), (2) the NICA collider parameters [1]: $\beta \approx 1$, $R = 0.035$ m, $C = 336$ m, $q = 32$, $Z = 79$, $E_c \approx 1$ keV, we find for the necessary condition — $N_{b,\mathrm{neces}} = 5.2 \cdot 10^8$, and for the sufficient condition — $N_{b,\mathrm{suf}} = 7 \cdot 10^9$.

Thus, such estimates show that NICA collider parameters are close to excite e-clouds development. Therefore numerical simulations have been fulfilled.

2. THE SIMULATION CODE

The preliminary estimates for e-cloud buildup for NICA were made using «ECLOUD code, version 3.2, 2005» developed by F. Zimmermann (see [1]). Presently, the new «version 3.3, 2009» of this code is available [6]. It gives rather good agreement with experimental results at SEY $= 1.53$ [7]. Therefore, the numerical simulations presented below were performed with this version of ECLOUD code.

3. NUMERICAL SIMULATIONS OF ELECTRON CLOUDS DEVELOPMENT IN NICA COLLIDER

At simulations we used SEY coefficient for stainless steel from Fig. 1, *b*, red curve, and cross section of residual gas ionization by $^{197}Au^{79+}$ ions from [8]. Other parameters are listed in the Table.

List of input parameters for e-cloud simulations

RMS beam emittance, $\pi \cdot$ mm $\cdot$ mrad	0.25
RMS bunch radius, mm	0.2
RMS bunch length, m	0.3
Dipole magnetic field, T	2
Vacuum chamber diameter, mm	60/70/75
Residual gas pressure, Torr	$5 \cdot 10^{-11}$
Ionization cross section $\sigma(H_2)/\sigma$ (CO), 10^{-15} cm^2 [8]	1.3/5.8

Special attention has been given to dipole sections, since in this case the conditions for e-cloud buildup are more stringent compared with the straight sections.

Simulation results (Fig. 2) were obtained for the bunch spacing in the range of 3.58 m $< S_b <$ 12.55 m for $\delta_{\max} = 1.5$ and 5.02 m $< S_b <$ 12.55 m for $\delta_{\max} = 2$.

The electron-cloudless working modes of NICA collider are given in Fig. 2 below the blue curve. The instability threshold can be defined using ECLOUD code with some uncertainty (the program itself becomes «unstable»). Therefore, the threshold is shown in Fig. 2 as a region marked by continuous color and is bounded by two curves — blue (continuous line) and red (dashed) ones.

It is pertinent to note here that both pairs of the curves in Fig. 2 do demonstrate a resonance character of the N_b threshold dependence on S_b. That agrees qualitatively with consideration given above (1), (2). However, the resonance width is very wide. This fact is connected with very wide dependence of SEY on primary electron energy (Fig. 1, a, b). Indeed, the condition of resonance has to be written taking into account initial velocity of secondary electrons and,

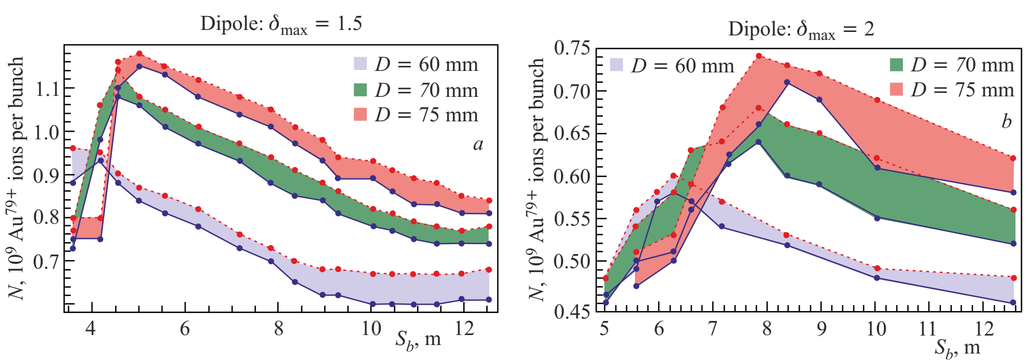

Fig. 2. Color online. Threshold values of $^{197}Au^{79+}$ ions per bunch vs. bunch spacing S_b for $\delta_{\max} = 1.5$ (*a*) and $\delta_{\max} = 2$ (*b*)

correspondingly, all the spectrum of SEY. All such nuances are included as we can hope in ECLOUD code.

Significant increase of the threshold ion number one can expect with reduction of SEY. For this purpose we began research on development of chamber-wall coating with TiN.

CONCLUSION

The working regimes of NICA collider are weakly dependent on the chamber material SEY for planned bunch spacing of 10 m.

For planned bunch spacing of 10 m, the SEY reducing from 2 to 1.5 increases maximum permissible luminosity approximately by a factor of 2.

At the moment of publishing of this article, the concept of NICA collider has undergone significant changes, therefore it needs to revise the presented above results for a new concept.

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