ELECTRON CLOUD SIMULATIONS FOR ANKA

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Abstract

One of the key issues for the developments of superconducting insertion devices is the understanding of the beam heat load in the vacuum chamber. The beam heat load observed in the superconducting cold bore undulator installed in the ANKA storage ring is higher than the one predicted by the synchrotron radiation and resistive wall heating. A non linear increase of the dynamic pressure with the beam current is also observed in the cold bore. In order to investigate whether the nature of these effects is due to an electron cloud formation, we have performed several simulations using the ECLOUD code.

INTRODUCTION

The cold bore superconducting undulator (SCU) installed at ANKA in March 2005 has been showing a nonlinear increase of the pressure rise and heat load with the beam intensity (see Fig. 1). Since then, several studies have been performed to analyze the reason of this pressure rise and heat load, being the electron bombardment a consistent reason for these phenomena [1] .

A common cause for the electron bombardment is the build-up of an electron cloud, which strongly depends on the chamber surface properties. This paper shows the simulations carried out using the ECLOUD code [2] to study the plausibility of an electron cloud build up at the SCU.

The results are compared with measurements using an electron detector located in a room temperature chamber located downstream the SCU. Figure 2 shows the location of the SCU and the electron detector, both downstream a bending dipole. The scraper located between the dipole decreases the synchrotron radiation flux to the SCU. Unfortunately, the undulator is not equipped with an electron detector and thus the nature of the electron bombardment at the cold bore is unclear.

Therefore, the goal of the simulations are 1) to explore the surface chamber conditions that can produce an electron cloud at the SCU, and 2) to check if the simulated electron flux follows a similar evolution than the one observed using the electron detector.

ELECTRON CLOUD SIMULATIONS

We have performed simulations scanning several ECLOUD input parameters with respect to a reference case. Table 1 shows the reference value and the scan range for

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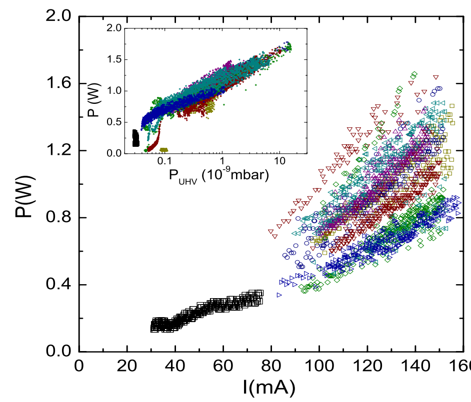

Figure 1: Observed heat load and pressure at the SCU [1].

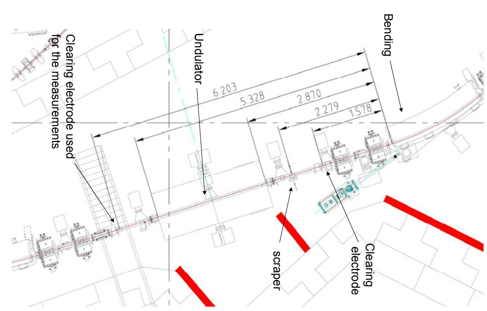

Figure 2: Layout location of the SCU and surrounding elements.

each parameter. Note that we have scanned the surface parameters even with uncommonly large values of the surface parameters because a cold bore (T=4.2 K) surrounded by room temperature conditions readily contaminates its surface by cryosorption [3]. Under these circumstances, the cold bore surface status and its SEY are uncertain.

Figure 3 shows six plots that summarize the output of the performed ECLOUD simulations. The top row plots show the heat load as a function of the bunch passage, the bottom row shows the average electron density as a function of the scanned parameter: beam intensity (first column), maximum SEY $\delta_{\max}$ (middle column), and primary electron yield N_{pe} (third column). The output of the simulations done scanning other input parameters (δ_0, $E_{\max}$, and vertical aperture) are not shown since the results (in terms of heat load and electron density) are similar to the ones in

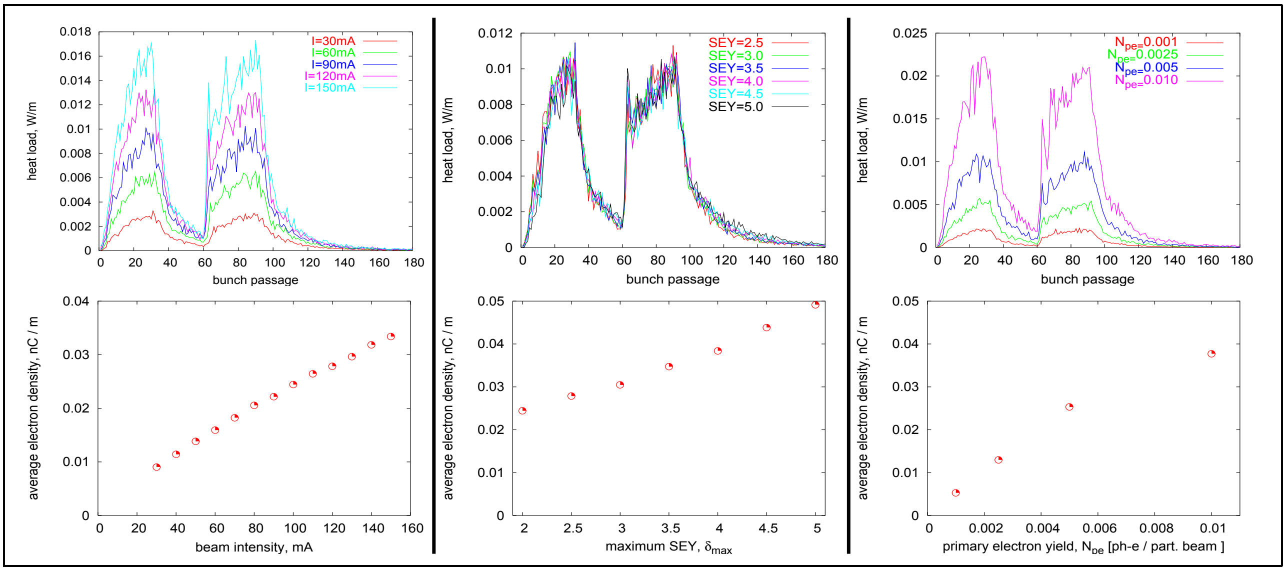

Figure 3: **Top row**: heat load evolution during one turn scanning the beam intensity (left), $\delta_{\max}$ (middle), and N_{pe} (right). **Bottom row**: average electron density scanning the beam intensity (left), $\delta_{\max}$ (middle), and N_{pe} (right).

Table 1: ECLOUD Input Parameters

Parameter	ref. value	scan
beam intensity (mA)	100	30 - 150
bunches / train	32	...
# trains	2	...
bunch charge (e-)	3.5e9	(1 - 5.4)e9
bunch spacing (ns)	2	...
energy (GeV)	2.5	...
rev. period (ns)	360	...
hor beam size (mm)	0.840	...
ver beam size (mm)	0.063	...
long beam size (mm)	12	...
hor aperture (mm)	80	...
ver aperture (mm)	30	8 - 30
SEY at zero energy, δ_0	0.5	0.5 - 0.9
max SEY, $\delta_{\max}$	2.0	1.5 - 5
energy for $\delta_{\max}$ (eV)	290	150 - 290
peak energy ph-e (eV)	7.0	...
energy ph-e, sigma (eV)	5.0	...
energy ph-e, sigma (eV)	1.8	...
primary e- yield, N_{pe} (ph-e/part. beam)	0.005	0.001- 0.01

Fig. 3, and do not change the conclusions drawn from this analysis.

The top row shows that even for the maximum value obtained in the simulations (20 mW/m considering $N_{pe} = 0.01$), the heat load is a factor ∼25 lower than the one measured in the SCU. In general, the heat load is in the order of 10 mW/m, and considering that the SCU is 2 m long, we can conclude that the simulated heat load is between 1 and 2 orders of magnitude lower than the measured one.

The dependence of the electron density with the beam intensity and the maximum SEY, $\delta_{\max}$, follows a linear dependence. We would like to stress that the heat load is not affected by the maximum SEY (top middle plot), and that not even for $\delta_{\max} = 5$ (an unusually high value of SEY) the heat load surpasses the 10 mW/m range. As we can see in Fig. 4, there are barely no electrons with energies larger than 40 eV, for which the SEY is lower than unity. This indicates that the energy gain per bunch passage is not enough to produce multipacting, i.e. the secondary electrons do not dominate the cloud electrons in the SCU. This suggests that the main source of electrons comes from the primary electrons.

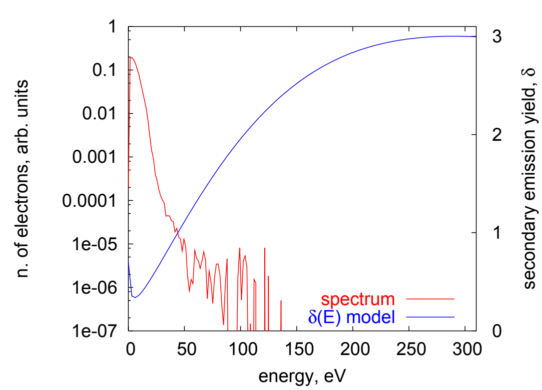

Figure 4: Energy spectrum obtained with the ECLOUD code for the case with $\delta_{\max} = 3$, and model of $\delta(E)$. The spectrum is dominated by electrons whose $\delta(E) < 1$.

Primary Electrons

The parameter N_{pe} has a big relevance on the heat load and the electron density (see plots at third column in Fig. 3). The ECLOUD input parameter that accounts for the primary electrons per particle beam created on the vacuum chamber is N_{pe}. In this case, it shall be computed taking into account the synchrotron radiation photons produced by the upstream dipole [2]:

$$N_{pe} = \left(\frac{d\phi}{d\theta_x}\right)\Delta\Theta_x Y_{pe} = \left(\frac{5}{2\sqrt{3}}\alpha\gamma\right)\Delta\Theta_x Y_{pe}, \quad (1)$$

where α is the fine structure constant, $\gamma = E/(m_e c^2)$ is the beam energy in units of rest energy, and $\Delta\Theta_x$ is the deflection angle that irradiates the 1.8 m of the SCU from the upstream magnet. The parameter Y_{pe} is a chamber surface parameter and represents the number of photoelectrons created when a photon hits the chamber and typically varies between 0.01 and 0.1 [4, 5].

From Eq. 1, one can see that the consequence on ECLOUD of increasing by a factor of 2 the parameter Y_{pe} is analogous to physically assume that the deflection angle $\Delta\Theta_x$ increases a factor of 2. This aperture has been considered $\Delta\Theta_x = 1$ mrad throughout the study, which is a pessimistic estimation because the scraper between the dipole and the SCU limits this aperture.

COMPARISON WITH EXPERIMENTAL RESULTS

Since 2007, an existing clearing electrode was located downstream the SCU in a room temperature vacuum chamber [6]. The measured electron flux has been compared with the one obtained using the simulations for 1, 2 and 3 trains in the machine. Since the electron beam repels the cloud electrons from the center, it is important to obtain the e-flux distribution along the horizontal position [7].

These simulations have been carried out using the same input parameters as shown in Table 1. The electron detector measurements and the results obtained in the simulations are shown in Fig. 5. In order to compare the both data in the same plot, the electron flux obtained using ECLOUD has been divided by a factor 5.

We can see that the electron flux at the center of the vacuum chamber shows a stronger saturation for 1-train because the bunch charge is larger than with 2 or 3-trains. The electron flux behaviour compares relatively well for 2 and 3 trains, and shows a larger discrepancy for the 1-train case. The absolute values in simulations are larger by a factor ∼5 than the measured in the clearing electrode. However, we can see that the measurement is strongly sensitive to the bias voltage of the clearing electrode (see Fig. 2 in Ref. [6]).

SUMMARY

The heat load inferred from the ECLOUD simulations is about one order of magnitude lower than the measurements

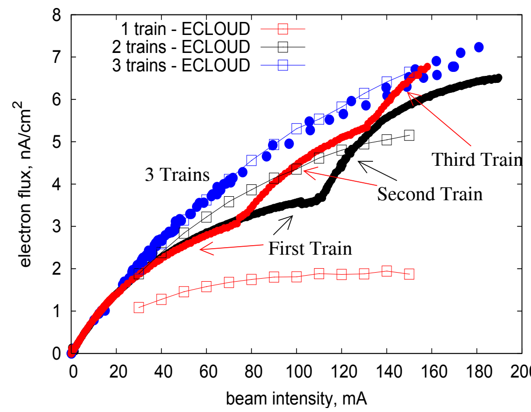

Figure 5: Electron flux comparison between the ECLOUD simulations (hollow squares) and measured at the e-detector (bold dots) for 1, 2 and 3 trains. The flux using ECLOUD simulations has been divided by 5 to show the results in the same plot.

(∼20mW vs ∼500mW). The energy spectrum shows that there are barely no electrons above ∼40 eV, which explains why multipacting is not found even for $\delta_{\max} = 5$. The most relevant ECLOUD input parameter is the primary electrons produced when the photoelectrons impinge the chamber wall (parameter N_{pe}), which produces a heat load of ∼40 mW (considering the 2 m length of the SCU). The comparison with the electron flux measured at the room temperature electron detector shows a relatively good agreement except for the case of 1-train.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. Casalbuoni et al. *Beam heat load and pressure rise in a cold vacuum chamber*, PRST-AB, 10, 093202, 2007.

[2] G. Rumolo and F. Zimmermann, *Practical User Guide for ECLOUD*, CERN SL-Note-2002-016.

[3] V. Baglin and B. Jenninger. *Gas condensates onto LHC type cryogenic vacuum system subjected to electron cloud*, Proc. of EPAC04, Lucerne (Switzerland), 2004.

[4] H. Fukuma and L. Wang. *Simulation of e-cloud instability at SuperKEKb*, Proc. of PAC05, Alburquerque (USA), 2005.

[5] F. Zimmermann, *Electron cloud studies for KEKb and ATF*, ATF Int. Report, 03-03, 2003.

[6] S. Casalbuoni et al. *Direct detection of the electron cloud at ANKA*, Proc. of EPAC'08, Genoa (Italy), 2008.

[7] U. Iriso, S. Casalbuoni, G. Rumulo, and F. Zimmermann. *Electron cloud simulations for ANKA*, presentation at ECM'08, Geneva (Switzerland), 2008.