OBSERVATIONS AND PREDICTIONS FOR DAΦNE AND SUPERB

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Abstract

In this paper the observations and simulations of the electron cloud induced instability in the DAΦne positron ring are presented. Predictions on electron cloud build-up and induced instability in the SuperB High Energy Ring are obtained through a simulation study.

INTRODUCTION

Under certain conditions, electrons can accumulate in the vacuum chamber of a positron storage ring. Primary electrons are generated by the interaction of beam synchrotron radiation with the chamber walls or by ionization of residual gas. These primary electrons produce secondary electrons after impact with the vacuum chamber walls. An electron cloud develops if beam and chamber properties are such to generate secondaries at a sufficiently high rate. Depending on the electron density level, the interaction between the cloud and beam may lead to detrimental effects such as single-bunch and coupled-bunch instabilities. Electron cloud effects have been a limitation for the DAΦne Φfactory, requiring installation of solenoids and clearing electrodes [1] to suppress the build-up of the cloud, and are expected to be a serious issue in the SuperB positron (HER) ring. In this communication simulation results relative to the coupled-bunch instability induced by the electron cloud buildup in the arcs of the DAΦne positron ring are reported and compared to experimental observation in the next section. Following we present estimates, based on numerical simulations, of the cloud density at which single-bunch instability is expected to set in, and of the density levels of the electron cloud in the SuperB High Energy Ring (HER). Conclusions follow in the last section.

ELECTRON CLOUD IN THE DAΦNE POSITRON RING

After the 2003 shutdown for the FINUDA detector installation, and some optics and hardware modifications, the appearance of a strong horizontal instability for the positron beam at a current $I \approx 500mA$, triggered the study of the e-cloud effect in the DAΦne collider. Experimental observation that seems to provide an evidence that the electron cloud effects are present in the DAΦne positron ring can be summarized as follow: a larger positive tune shift is induced by the positron beam current [2]; the horizontal instability rise time cannot be explained only by the beam interaction with parasitic HOM or resistive walls and increase with bunch current [3]; the anomalous vacuum pressure rise with beam current in positron ring [4], bunch-by-bunch tune shifts measured along the DAΦne bunch train present the characteristic shape of the electron cloud build-up [5]. There are also indications that wigglers play an important role in the instability, since the main changes after the 2003 shutdown were the modification of the wiggler poles, and lattice variation which gave rise to an increase of the horizontal beta functions in wigglers [6]. Recently the horizontal feedback for the DAΦne positron ring has been successfully upgraded [7] by doubling the entire system and allowing to operate the machine at a positron current higher than $1A$.

To better understand the electron cloud effects and possibly to find a remedy, a detailed simulation study has been performed [8], [9].

Electron Cloud Induced Coupled-Bunch Instability

Once the electron cloud is formed, the beam passing through the cloud interacts with it. The motions of bunches become correlated with each other if the memory of a previous bunch is retained in the electron cloud -i.e., a small displacement of a bunch creates a perturbation of the electron cloud, which affects the motions of the following bunches, with the result that a coupled-bunch instability is caused. A complete discussion of the electron cloud induced multi-bunch instability formalism is outside the aim of this paper . The reader is referred to [10] for a detailed presentation of the subject. Experimental observations [2]-[6] show that the horizontal instability affecting the DAΦne positron beam is a multi-bunch instability. The observed oscillation mode of the instability is always a very slow frequency mode and can be identified as the -1 mode, i.e., the mode that has a line closest to the frequency origin (zero frequency) from the negative part of the spectrum. The same behaviour has been observed even after the solenoid installation [7]. For this reasons the attention has been focused on the interaction of the beam with the cloud in wigglers and bending magnets where the solenoids are not effective.

Simulations for DAΦne

To estimate the multi-bunch instability induced by the electron cloud in the arcs of the DAΦne positron ring the code PEI-M [11],[12] has been used. The code computes the transverse amplitude of each bunch as a function of time, while evolving the build-up of the electron cloud self-consistently. To save computation time, the Poisson equation for the space charge potential is solved only once for

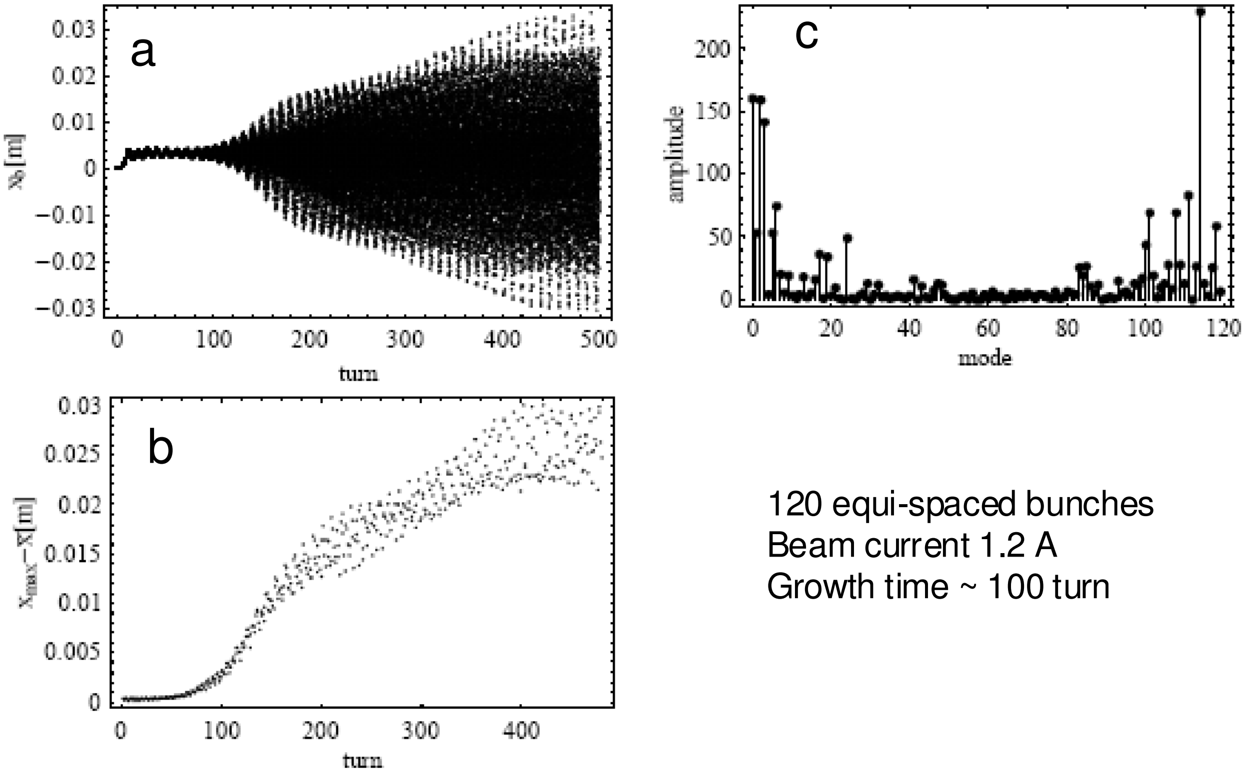

Figure 2: Beam signal (a), beam envelope (b), and mode spectrum (c) for a completely filled DAΦne bunch train.

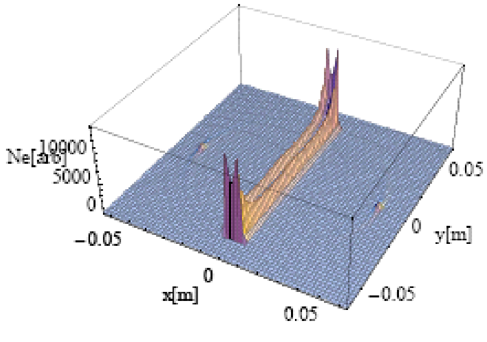

Figure 1: Typical electron cloud distribution in the transverse x-y plane. The number of electrons in an arbitrary unit is plotted in the vertical axis, as obtained by PEI-M after the first bunch train passage in a DAΦne arc bend.

Table 1: DAΦNE beam and pipe parameters used as input for ECLOUD simulations.

parameter	**unit**	**value**
bunch population N_b	10^{10}	2.1
number of bunches N	–	100
missing bunches N_{gap}	–	20
bunch spacing L_{sep}	m	0.8
bunch length σ_z	mm	18
bunch horiz. size σ_x	mm	1.4
bunch vert. size σ_y	mm	0.05
wiggler chamber horiz. aperture $2h_x$	mm	120
wiggler chamber vert. aperture $2h_y$	mm	20
straight sections radius	mm	44
primary photo-emission yield $d\lambda/ds$	–	0.0088
photon reflectivity	–	50%
maximum SEY δ_{max}	–	1.9
energy for max. SEY E_{max}	eV	250

zero beam amplitude, and is used as a constant field in tracking simulation. The beam and chamber parameters used in the simulation are collected in Table 1. A uniform vertical magnetic field $B_z = 1.7$ T was used to model the motion of the electrons both in wigglers and dipoles, and a circular chamber of radius $R = 45mm$ is used instead of the real chamber geometry in order to solve analytically the Poisson equation for the space charge potential Φ . In these tracking simulations, the motion of bunches filling the DAΦne positron ring while interacting with the cloud is followed for 500 turns. The instability mode spectrum is obtained by taking the Fourier transform of the transverse amplitude of each single bunch as computed by the code, and the grow-rate is obtained by an exponential fit to the beam signal envelope. In Figure 1 is shown a snapshot of the electron cloud distribution in the transverse x-y plane, as obtained bu the simulation code at the end of the first bunch train turn, assuming a uniform illumination of the beam chamber walls. The two stripes structure, typical of e-cloud distribution in strong bending field, is clear. In Figure 2 are reported the beam signal (the horizontal position of each bunch as a function of time expressed in turns), the beam signal envelope, and the mode spectrum obtained for a bunch train of 120 equi-spaced bunches filled with a beam current of 1.2 A. It is clearly seen that the most unstable mode, obtained by the simulation is mode 114, corresponding to the -1 mode. Experiments on coupled-bunch instabilities have been extensively performed using the DAΦne fast feedback system to perform grow-dump measurements [2],[3],[7]. Measured grow-rate are compared to simulation results in Table 2 for different beam currents, showing a good agreement. In order to suppress the e-cloud it has been decided to insert special metallic electrodes in the dipoles and the wigglers. A detailed description of the electrodes and the results of the recent extensive measurement campaign at DAΦne have been presented by M. Zobov and can be found in [1].

Table 2: Measured and simulated instability growth rate for different beam current.

Measurement		Simulation	
$I[mA]/nb$	τ/T_0	$I[mA]/nb$	τ/T_0
1000/105	73	1200/120	100
750/105	56	900/120	95
500/105	100	600/120	130

ELECTRON CLOUD IN SUPERB HER

For a complete evaluation, both the build-up of the cloud and its effects on the beam must be considered. In the following are presented estimates, based on numerical simulations, of the cloud density at which single-bunch instability is expected to set in, and of the density levels of the electron cloud in the SuperB HER.

Table 3: Input parameters for CMAD simulations.

Parameter	Unit	Value
Beam energy E	GeV	6.7
circumference L	m	1370
bunch population Nb	-	$5.74 \cdot 10^{10}$
bunch length σ_z	mm	5
hor. emittance σ_x	nm	1.6
vert. emittance σ_y	pm	4
hor./vert. bet. tune Qx/Qy	-	40.57/17.59
synchrotron tune Qz	-	0.01
hor./vert. av. beta function	m	20/20
momentum compaction α	-	$4.04 \cdot 10^{-4}$

Single Bunch Instability Threshold

In order to estimate with great accuracy the single-bunch instability threshold simulations have been performed with the strong-strong code CMAD [13]. In this code both the bunch and the electron cloud are represented by macroparticles, and the interactions between them are determined by solving a two-dimensional Poisson equation using the particle-in-a-cell method. Although the code can track the evolution of the instability trough a realistic lattice, here we assume that the interaction between beam and cloud is localized at 40 positions uniformly distributed around the ring, assuming a uniform value of the β functions. Figure 1 shows emittance growth due to the interaction of the electron cloud with a bunch in the SuperB HER as obtained by CMAD using the input parameters collected in Table 1. Each line shows an emittance growth for various cloud densities. The threshold density is determined by the density at which the growth starts. From this numerical simulation, we determine that the instability starts at $\rho_e = 4 \cdot 10^{11} m^{-3}$.

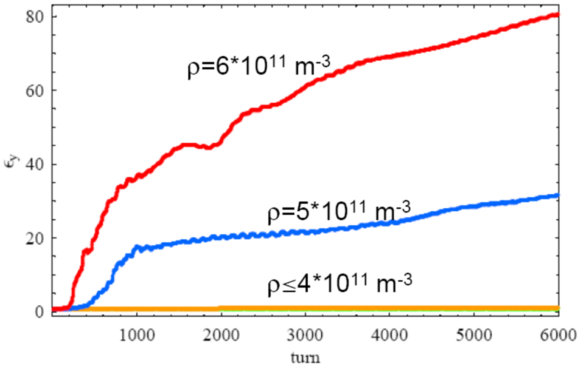

Figure 3: Emittance growth due to the single-bunch instability caused by the electron cloud effect.

Electron Cloud Buildup

We have used the simulation code ECLOUD [14] to evaluate the contribution to the electron cloud build-up in the arc bends of SuperB. The KEKB and PEP-II B Factories have adopted external solenoid fields to mitigate the electron cloud effect in field-free regions, which constitute a large fraction of the rings. In magnetic field regions, external solenoid fields are not effective in suppressing the build-up of the electron cloud. Thus, we have focused our simulations on the build-up of an electron cloud in the arc bend regions. We have assumed a vacuum chamber with an antechamber design and, in order to take into account the reduction of electron yield by the ante-chamber, we used a reduced number of primary electrons:

$$e^-/e^+/m = \frac{dn_\gamma}{ds} Y(1-\eta) \qquad (1)$$

where dn_γ/ds is the average number of emitted photons per meter per e^+, Y is the quantum efficiency, and η is the percentage of photons absorbed by the antechambers. In Table 4 are reported the saturation values of the electron cloud central densities (i.e., within a region of $10\sigma_x \times 10\sigma_y$ around the beam center) as obtained from ECLOUD for different values of the peak secondary emission yield (SEY) and of the antechamber protection factor η. Simulation were performed for a typical SuperB bending magnet, assuming a uniform vertical bending field $B_y = 0.5T$ and an elliptical chamber geometry with horizontal and a vertical aperture $95mm$, and $55mm$ respectively.

Table 4: Electron cloud densities from ECLOUD simulations.

SEY	η	$rho_e[10^{12}e^-/m^3]$
1.1	95%	0.4
1.1	99%	0.09
1.2	95%	0.9
1.2	99%	0.2
1.3	95%	8.0
1.3	99%	4.0

The density values given in Table 4 have to be scaled by the ”filling” factor of dipoles (i.e., the fractions they cover the ring), which amount to about 0.5. The results show that a that a peak secondary electron yield of 1.1 and 99% antechamber protection result in a cloud density below the instability threshold. In this scenario the adoption of mitigation techniques to keep the e-cloud density level below the instability threshold are essential. Following the example of the ILC [15] and SuperKEKB [16] collaborations a datailed study of a range of mitigation options including coatings, clearing electrodes, grooves and novel concepts should be performed taking into account the efficacy, cost, and possible impact on the machine of the proposed mitigation scheme.

CONCLUSIONS

Coupled-bunch instability simulations are in good agreement with the experimental observations, and indicate that the observed horizontal instability is compatible with a coupled bunch instability induced by the presence of an electron cloud in the arcs of the DAΦne positron ring. Work is in progress to include more realistic models for the space charge potential and the chamber boundaries in the simulation code.

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