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COLLECTIVE EFFECTS IN THE SUPERB COLLIDER

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Abstract

Some collective effects have been studied for the SuperB [1] high luminosity collider. Estimates of the effect of Intra Beam Scattering (IBS) on the emittance and energy spread growths have been carried up for both the High Energy (HER, positrons) and the Low Energy (LER, electrons) rings. Electron cloud build up simulations for HER were performed with the ECLOUD code, developed at CERN [2], to predict the cloud formation in the arcs, taking into account possible remediation techniques such as clearing electrodes. The new code CMAD, developed at SLAC [3], has been used to study the effect of this electron cloud on the beam and assess the thresholds above which the electron cloud instability would set in.

Table 1: 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	-	$4.04 \cdot 10^{-4}$

ELECTRON CLOUD IN SUPERB HER

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 B-factories, requiring installation of solenoids to suppress the build-up of the cloud, and are expected to be a serious issue in the SuperB positron (HER) ring. For a complete evaluation, both the build-up of the cloud and its effects on the beam must be considered. In the 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 HER.

Single Bunch Instability Threshold

In order to estimate with great accuracy the single-bunch instability threshold we performed simulation with the strong-strong code CMAD [3]. In this code both the bunch and the electron cloud are represented by macro-particles, 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 $\rho_e = 4 \cdot 10^{11} m^{-3}$.

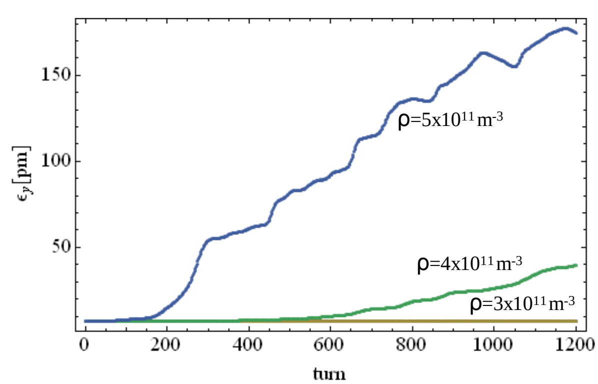

Figure 1: Emittance growth due to the single-bunch instability caused by the electron cloud effect.

Electron Cloud Buildup

We have used the simulation code ELOUD [2] 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, ex-

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ternal 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 2 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 2: 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 2 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 1.2 and 99% antechamber protection result in a cloud density close to the instability threshold.

INTRABEAM SCATTERING

Intrabeam scattering [4, 5] is associated with the Touschek effect; while single large-angle scattering events between particles in a bunch leads to loss of parti- cles (Touschek lifetime), multiple small-angle scattering events lead to emittance growth, an effect that is well known in hadron colliders and referred to as intrabeam scattering (IBS). In most electron storage rings, the growth rates arising from IBS are usually very much longer than synchrotron radiation damping times, and the effect is not observable. However, IBS growth rates increase with increasing bunch charge density, and for machines that operate with high bunch charges and very low vertical emittance, the IBS growth rates can be large enough that significant emittance increase can be observed. Qualitative observations of IBS have been made in the LBNL Advanced Light Source [6], and measurements in the KEK Accelerator Test Facility (ATF) [7] have been shown to be in good agreement with IBS theory.

Several formalisms have been developed for calculating IBS growth rates in storage rings, notably those by Piwinski [4] and by Bjorken and Mtingwa [5]. IBS growth rates depend on the bunch sizes, which vary with the lattice functions around the ring; to calculate accurately the overall growth rates, one should therefore calculate the growth rates at each point in the lattice, and average over the circumference. Furthermore, since IBS results in an increase in emittance, which dilutes the bunch charge density and affects the IBS growth rates, it is necessary to iterate the calculation to find the equilibrium, including radiation damping, quantum excitation and IBS emittance growth. The full IBS formulae include complicated integrals that must be evaluated numerically, and can take significant computation time; however, methods have been developed [5, 6] to allow reasonably rapid computation of the equilibrium emittances, including averaging around the circumference and iteration.

For calculation of the IBS emittance growth in the SuperB rings, we use the formulae of Kubo et al. [9], which are based on an approximation to the Bjorken-Mtingwa formalism [5]. This approximation has been shown to be in good agreement with data on IBS emittance growth collected at the ATF [7]. In our calculations, the average growth rates are found from the growth rates at each point in the lattice, by integrating over the circumference; we use iteration to find the equilibrium emittances in the presence of radiation and IBS.

Figure 2 shows the equilibrium transverse emittances, bunch length and energy spread in the SuperB rings as functions of the bunch charge. In the LER at the nominal bunch charge of $6.5 \cdot 10^{10}$, the horizontal emittance is nearly 30% higher, there is also an increase in the vertical emittance 35%. The increase in transverse emittances is significant, but still below the design values indicated bi the dashed lines in figure. The strong scaling of IBS growth rates with energy means that in the HER the emittance growth from IBS is much less than in the low energy ring; the effects of IBS are further mitigated by the lower bunch charge in the high energy ring. There is a 11% increase in horizontal emittance at the nominal bunch charge of $5.5 \cdot 10^{10}$ particles, and an increase in vertical emittance of about 5%.

CONCLUSIONS

We estimated the effect of electron cloud and IBS for the SuperB collider. Build up and instability simulations show that the electron cloud is a serious issue for the SuperB HER. An antechamber absorbing 99% of the synchrotron radiation and a maximum SEY of the surface be-

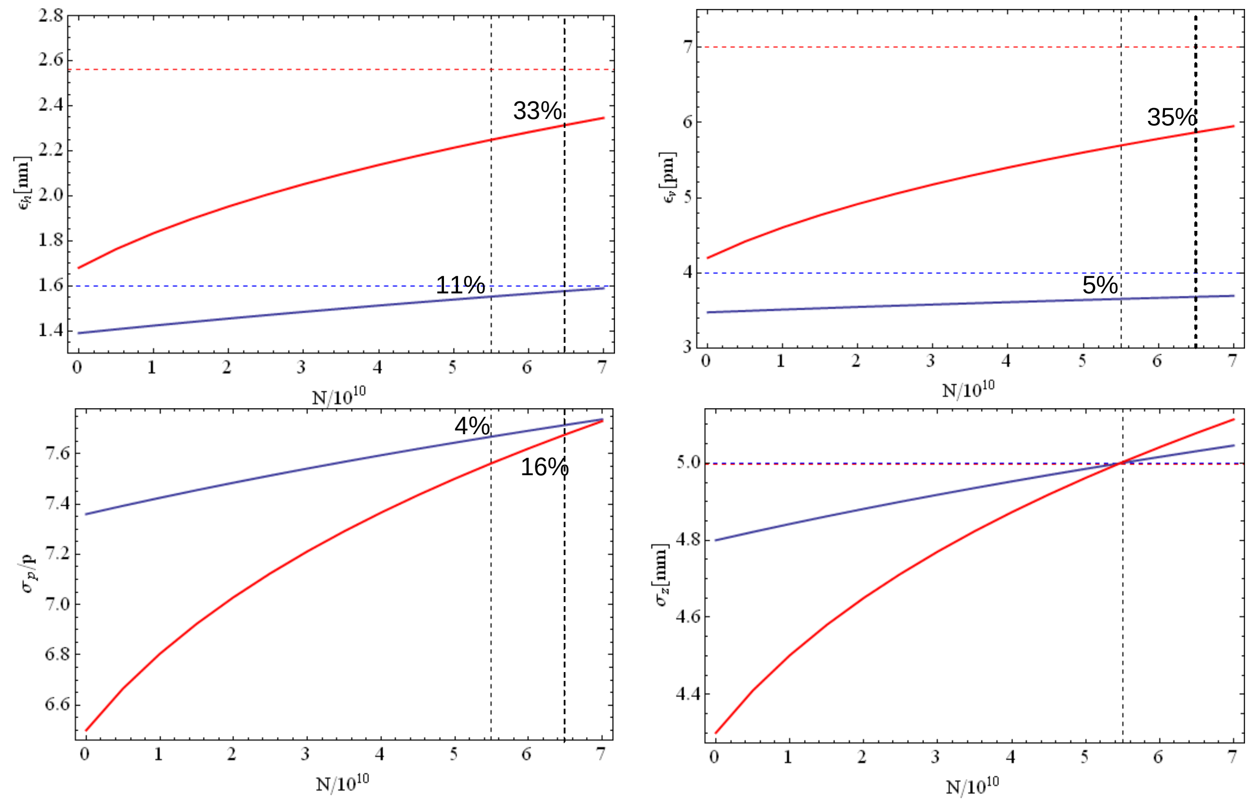

Figure 2: Transverse emittance growth, and growth in bunch length and energy spread in the SuperB LER (red) and HER (blue), as functions of the bunch charge.

low 1.2 could ensure stable operation because it would prevent electron cloud formation and its detrimental effect on the positron beam. Calculations based on a high energy approximation of the Bjorken-Mtingwa formalism show that IBS should be manageable in both SuperB rings. However there are still some interesting aspect to explore such as the impact of IBS during the damping process and its effect on beam distribution. Work in this direction is on order.

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