MULTIPARTICLE SIMULATION OF INTRABEAM SCATTERING FOR SUPERB

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Abstract

In this communication we present the structure of a multiparticle tracking code to investigate intrabeam scattering effects in low emittance colliders. Simulation results obtained with particular reference to the SuperB parameters are compared with those of conventional IBS theories.and with those of a novel semi-analythical model able to predict IBS effect in terms of emittance growths.

INTRODUCTION

Intrabeam scattering (IBS) is associated with multiple small angle scattering events leading to emittance growth. In most electron storage rings, the growth rates arising from IBS are usually much longer than damping times due to synchrotron radiation, and its effect is not observed. However, IBS growth rates increase with bunch charge density, and for machines such as SuperB [1], that operate with high bunch charges and very low emittances, the IBS growth rates can be large enough to observe significant emittance increase.

Several formalisms have been developed for calculating IBS growth rates in storage rings, notably those by Piwinski [2], Bjorken and Mtingwa [3], and their high energy approximations [4]. Calculations show that IBS should be manageable in both SuperB rings [1]. However these analytical models, based on Gaussian bunch distributions, cannot investigate some interesting aspects of IBS such as its impact during the damping process and its effect on the beam distribution. We developed a multiparticle tracking code, based on the Zenkevich-Bolshakov algorithm [4], to investigate these effects. In this communication we present the structure of the code and some simulation results obtained with particular reference to the SuperB parameters. Simulation results are compared with those of conventional IBS theories.

SIMULATION TOOL

To simulate the IBS effect we adopted the macroparticle algorithm, based on the binary collision model (BCM) [4], introduced in [5]. The steps of this algorithm can be summarized as follows:

1. An initial (Gaussian) distribution of the macroparticles is generated at a chosen location in the ring.
2. The macroparticles are grouped into different cells according to their positions in space.
3. The macroparticles in the same cells are paired randomly to collide with each other. The momentum changes due to collisions are evaluated according to Piwinski formulas [1,5].
4. The beam emittances caused by the IBS in this element are computed.
5. Macroparticles are tracked to the next element.
6. Steps 2 to 5 are repeated for the next lattice element.
7. At the end of each turn radiation damping and quantum excitation are computed.

Although we focused on initial Gaussian beams, the algorithm could also be used for particle beam with an arbitrary distribution.

The code uses as input the MAD generated files “sectormap” and “optics”. Sectormap and optics files respectively include the information on the first and second order transfer maps and the Courant-Snyder lattice parameters for each element of the ring. The beam is then tracked along the ring by first order 6D R transfer maps.

Typical outputs of the code are the beam emittances evolution, beam losses distribution at each machine element and the final bunch distribution. The simulation code can also track the emittances along the lattice to check in which elements IBS effect is stronger.

NUMERICAL RESULTS

We used this code to simulate the IBS effects in the SuperB collider. In particular, in view of the strong scaling of IBS growth rates with energy, we focused our attention on the low energy ring (LER). Simulations have been performed with the parameters specified in Table 1 (i.e. for the zero current equilibrium emittance) and for the latest lattice reported in [1].

Table 1: Input parameters

Parameter	Unit	Value
Energy	GeV	4.18
Bunch population	10^{10}	6.5
Circumference	m	1257
Emittances (H/V)	nm/pm	1.82/4.55
Bunch Length	mm	3.99
Momentum spread	%	0.0667
Damping times (H/V/L)	ms	40/40/20
N. of macroparticles	-	10^5
N. of grid cells	-	64x64x64

The evolution of the horizontal emittance over one turn under the influence of IBS only (bottom panel) and the corresponding β-functions of the ring (top panel) are shown in figure 1. It appears from the plots that the emittance increase is larger in the final focus (FF), as expected due to small beam sizes in this region. Outside the FF the increase appears quite constant, due to the periodicity of the lattice.

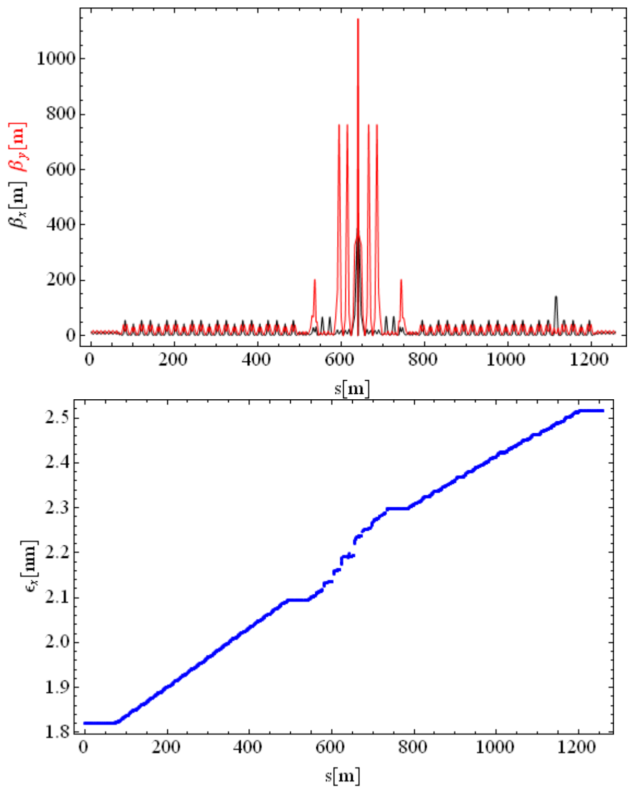

Figure 1: Beta functions of SuperB LER (top panel), horizontal emittance evolution along the ring under the influence of IBS (bottom panel). The final focus region is between 500-700 m.

The evolutions of horizontal and longitudinal emittances for different values of the bunch population are reported in figure 2. For all these values the beam emittance evolution, taking into account both IBS and radiation effects, has been tracked over roughly 10 horizontal damping times (10^5 turns). The emittance reaches saturation equilibrium after a few damping times for all the cases.

SEMI-ANALYTICAL MODEL

Simulations based on the multipartcle tracking code, while providing a detailed description of the emittance evolution, require a large amount of CPU time: a complete simulation can last from a few hours to several days

An alternative easily computable semi-analytical approach which allows a quick scan of some key design parameters, such as the bunch population, is presented in the following.

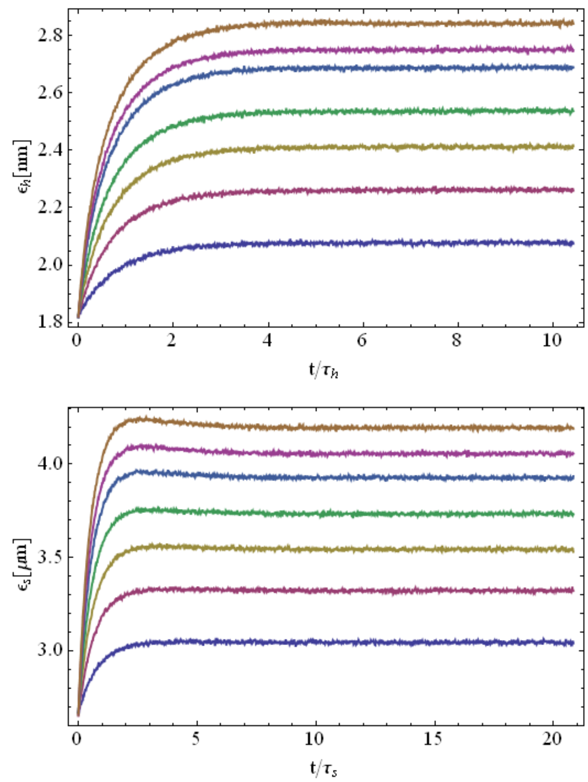

Figure 2: Evolutions of horizontal (top) and longitudinal (bottom) emittances for different values of the bunch populations.

Radial and longitudinal emittance evolutions are calculated for different bunch intensities by the Monte Carlo simulation and then fitted to the emittance growths predicted by a model that takes the form of a coupled differential equations:

$$\begin{cases} \dot{\varepsilon}_x = -\dfrac{1}{\tau_x/T_{rev}}\left(\varepsilon_x(t)-\varepsilon_{xeq}\right)+\dfrac{Na}{\varepsilon_x^{3/4}(t)\varepsilon_z(t)} \\ \dot{\varepsilon}_z = -\dfrac{1}{\tau_z/T_{rev}}\left(\varepsilon_z(t)-\varepsilon_{zeq}\right)+\dfrac{Nb}{\varepsilon_x^{3/4}(t)\varepsilon_z(t)} \end{cases}$$

where N is the number of particles per bunch, while a and b are coefficients charaterizing IBS and are obtained by fitting the simulation data. τ_x and τ_z are horizontal and longitudinal damping times, T_{rev} is the revolution frequency, ε_{xeq}, ε_{zeq}, a, and b are unknown parameters extrapolated by fitting tracking simulation data. In particular, ε_{xeq}, $\varepsilon_{zeq,}$ which represent the equilibrium emittances for the unperturbed (no IBS) case, are obtained from the zero intensity case while the coefficients a and b, characterizing IBS, are obtained from the nominal bunch intensity case chosen as benchmark.

In figure 3 are reported the equilibrium values of longitudinal and horizontal emittance as a function of bunch charge obtained with three different approaches. The continuous line represents the analytic estimate based on the Bane model [4]; the blue triangles marks the tracking simulation results; while red squares indicate the equilibrium values extrapolated with the semi-analytic approach, the full mark corresponds to the (fitted) benchmark case. The agreement between the different approaches is very good in the explored range of parameters.

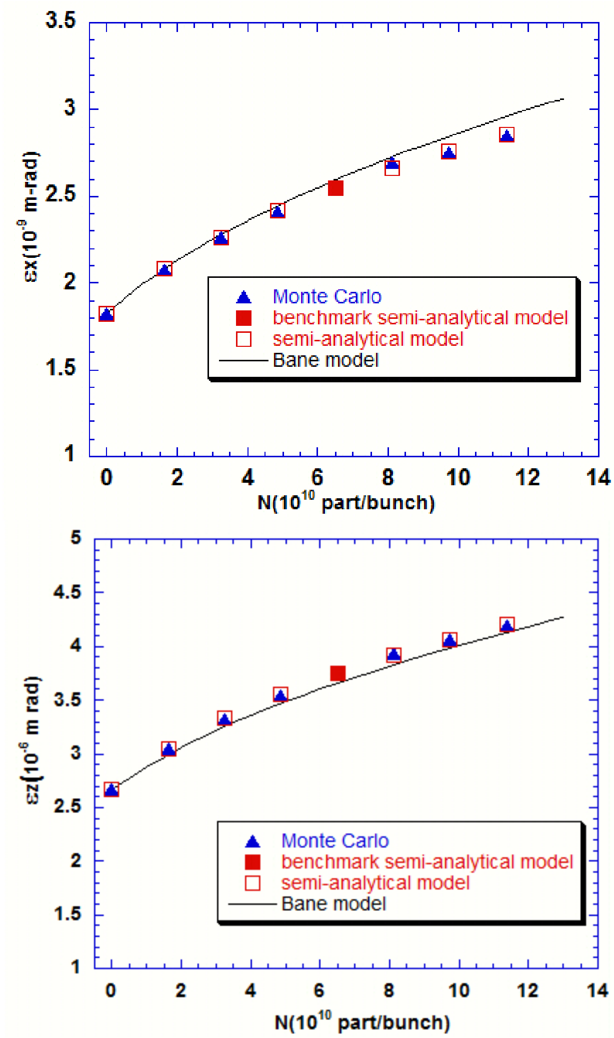

Figure 3: Comparison of the horizontal (top) and longitudinal (bottom) equilibrium emittances as functions of beam intensity.

CONCLUSIONS

Interesting aspects of the IBS such as its impact on damping process and on generation of non Gaussian tails may be investigated with a multiparticle algorithm.

Benchmarking with conventional IBS theories gave good results. The proposed semi-analytical model fits simulation results very well, being thus able to predict IBS effect at various bunch currents.

Developments such as the inclusion of coupling, vertical dispersion, detailed beam tails studies, and the limiting case of extremely small vertical beam emittance are planned.

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