INTRABEAM SCATTERING STUDIES AT THE SWISS LIGHT SOURCE

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Abstract

The target parameters of modern ultra-low emittance rings are entering into a regime where Intra-beam Scattering (IBS) becomes important and, in the case of linear collider damping rings, even a limitation for the delivered emittances. The Swiss Light Source (SLS) storage ring, as it has achieved a vertical geometrical emittance of around 1 pm at 2.4 GeV [1], and it has the ability to run at even lower energies, and the availability of emittance monitoring diagnostics, is an ideal testbed for IBS studies. Simulations are undertaken using the classical IBS theories and tracking codes in order to explore the possibilities and limitations for IBS measurements at the SLS. In this respect, comparison between the theories and codes is first discussed. The dependence of the output emittances, taking into account the effect of IBS, with respect to energy, bunch charge and zero current vertical and longitudinal emittance is also studied, in order to define the regimes where the IBS effect can be significant. First measurement results from the SLS are finally presented.

INTRODUCTION

Future e^+/e^- linear collider damping rings, b-factories and modern high brilliance light sources target ultra low emittances, entering in a regime where collective effects and especially intra-beam scattering (IBS) are predominant. IBS is a small angle multiple Coulomb scattering effect depending on the lattice and beam characteristics.

Several theories and their approximations [2–5] were developed over the years describing the effect. One of the main weaknesses of all theoretical models is the consideration of Gaussian beam distributions, whose preservation, especially in the case of strong IBS, is not evident. The generation of non-Gaussian tails and its impact on the damping process can only be investigated with multi-particle algorithms [6,7]. The benchmarking of these theoretical and numerical models with beam experiments would be the ultimate goal for understanding IBS.

The Swiss Light Source (SLS) storage ring is an ideal testbed for these experimental studies: a record vertical geometrical emittance of around 1 pm at 2.4 GeV was recently reached [1], but also, the ring has the ability to run at lower energies, where the IBS effect is strong and the availability of emittance monitoring diagnostics. In this paper, calculations are undertaken, using the IBS theories and tracking codes, in order to explore the possibilities and limitations for IBS measurements at the SLS. In this respect, comparison between theoretical models and codes is first discussed. The dependence of the output emittances on the equilibrium emittances is then studied. Finally, first measurement results from the SLS are presented.

IBS THEORY AND SIMULATIONS

The IBS theory for accelerators was first introduced by Piwinski giving a formulation which is called the standard Piwinski (P) [2] method, and was extended by Martini, and further by Bane to the often called Modified Piwinski (MP) approach. There are also several approximations developed over the years, in particular, the high energy one by Bane (Bane) [4] and the Completely Integrated Modified Piwinski (CIMP) [5] method. A different approach was followed by Bjorken and Mtingwa (BM) [3].

Recently, two multi-particle tracking codes were developed [6,7] which treat IBS, synchrotron radiation (SR) and quantum excitation (QE), regardless of the bunch distribution, giving the possibility to explore the generation of non-Gaussian tails. In this respect, the influence of IBS is

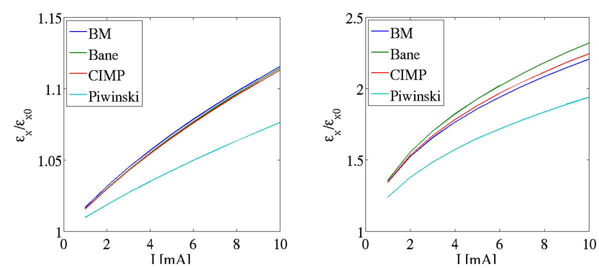

Figure 1: The IBS effect at the horizontal plane as calculated by Piwinski, B-M, Bane and CIMP at the nominal (left) and low energy (right) of the SLS.

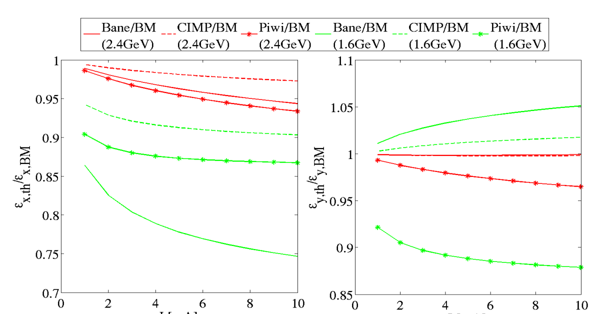

Figure 2: Horizontal (left) and vertical (right) emittance ratios for IBS models with respect to the BM method for nominal (red) and low energy (green) for different bunch currents.

estimated in the SLS ring through the different theoretical

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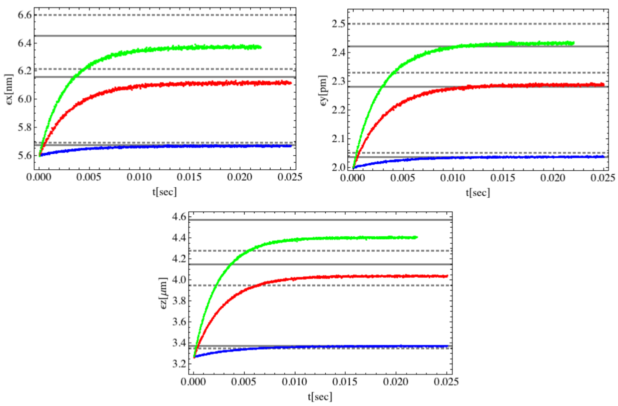

Figure 3: Evolution of horizontal (top, left), vertical (top, right), and longitudinal (bottom, left) emittances under the influence of IBS as obtained by the tracking code for different values of the bunch population: 6×10^9 (blue), 60×10^9 (red) and 100×10^9 (green). Horizontal lines represent the steady state values predicted by Piwinski (full) and Bane (dashed) models for the considered bunch populations.

models and codes mentioned above, and compared for the nominal (2.4 GeV) and lower energy (1.6 GeV).

Figure 1 shows the ratio of the horizontal steady state to zero current emittance versus current at 2.4 GeV (left) and at 1.6 GeV (right). There is an excellent agreement among all IBS theoretical models, with Piwinski's approach (light blue curve) differing by a maximum of 10% for the highest current and low energy.

Figure 2 displays the ratio of the horizontal (left) and vertical (right) emittances calculated by Bane (solid line), CIMP (dashed line) and Piwinski (starred line) to the one calculated by B-M which is used as a reference. The red lines refer to the nominal energy while the green to the lower one. The agreement between the theoretical models depends on the magnitude of the effect. For the nominal energy, where the effect is small, the agreement between the models is very good even at high currents, and always within less than 5% up to 10 mA for the horizontal and within 7% for the vertical plane. The longitudinal plane (not pictured) follows the trend of the horizontal one. For the low energy, the agreement of Bane, CIMP and BM is still very good for the horizontal plane but Piwinski seems to underestimate the effect with respect to the others. In the vertical plane B-M, CIMP and Piwinski agree within less than 15% while Bane is diverging, especially at high currents. This is due to the fact that Bane's approximation deviates from the IBS theories for zero or very low vertical dispersion [8], which is the case of the SLS ring.

In Figure 3, results obtained using the tracking code described in [7] are compared to the analytical model predictions, for different values of the bunch population, assuming nominal parameters for the 2.4 GeV configuration of the SLS ring. An initial distribution of 10^5 macro-particles has been generated at a particular location of the machine and the emittance evolution under the effect of IBS has been tracked for approximately 3 damping times, through a "realistic" model of the ring lattice. In all cases, at the end of the simulations the emittances approach steady state values that are very close to those predicted by the theoretical models. In particular, the Piwinski model seems to provide the closest emittance prediction with respect to the tracking results. This is expected as the IBS kicks used in the tracking code are based in the Rutherford cross section also employed by the approach of Piwinski.

IBS DEPENDENCE ON SLS PARAMETERS

All IBS models and codes provide the same trend in the emittance evolution. In principle, any of them could be used to study the dependence of the output emittances on the different other beam parameters. In what follows, the CIMP approximation is used for studying the IBS dependence on zero current vertical emittance, energy spread and bunch length.

At SLS, the turbulent bunch lengthening (TBL) dominates the high intensity regime, leading to both bunch length and energy spread increase. Its onset is observed at around 0.6 mA for the nominal energy [9]. Assuming that this effect is disentangled with scattering processes, different longitudinal equilibrium parameters can be estimated for each current. It is thus interesting to study how the steady states due to IBS depend on different equilibrium bunch length (σ_{s0}) and energy spread (σ_{p0}) values. Figure 4, shows the IBS effect on the horizontal emittance (left) and bunch length (right), at nominal energy, with respect to bunch current for different σ_{s0} values, each one represented by a different color curve. Due to TBL, the longitudinal parameters get increased, and the IBS effect, even at higher currents, is reduced, making the measurement at nominal energy quite difficult.

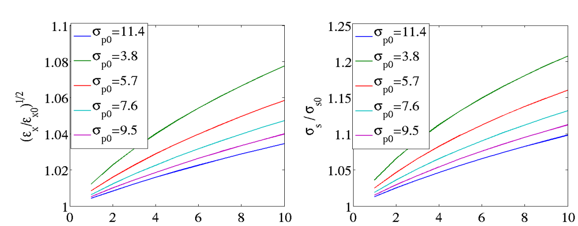

Figure 4: The IBS effect versus current in the horizontal emittance (left) and bunch length (right), for different equilibrium bunch lengths, at nominal energy.

As was already mentioned, the SLS has achieved a vertical geometrical emittance of around 1pm·rad at nominal energy. However, we cannot assume that this will be the case for the lower energy or for high currents. Figure 5 presents the IBS effect in all planes for different zero current vertical emittance, represented by curves of different colour. At low energy and even for large zero current vertical emittances and relatively low currents, the IBS effect is predicted to be appreciable.

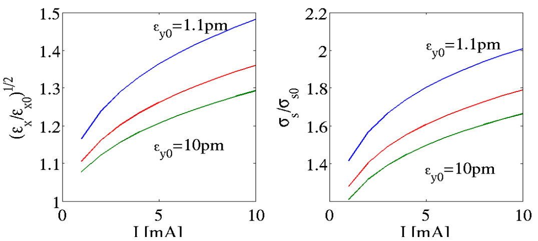

Figure 5: IBS growth versus current in the horizontal emittance (left) and in bunch length (right), at 1.6 GeV, for different equilibrium vertical emittance values.

MEASUREMENTS

A first set of measurements at the SLS storage ring, tuned at low energy, were recently performed. The horizontal and vertical beam size was measured with a synchrotron light beam size monitor, able to monitor very small beam sizes. The bunch length was measured with a streak camera. Details on the beam instrumentation at the SLS can be found in [10, 11]. As the pinhole camera is placed in a dispersive region, it is important to know the energy spread which changes due to the turbulent effect. A method of energy spread measurement through the height of the synchrotron sidebands is currently under study.

The machine was corrected at low current, achieving a vertical emittance of 3.4 pm·rad. Two set of measurements for different RF voltage settings, at 600 kV and 2000 kV, were taken. The measurements were repeated for large zero current vertical emittance, in order to suppress the IBS effect and measure the dependence of the bunch length with current due to TBL.

Figure 6 (top) shows the bunch length versus current at 600 kV (left) and at 2000 kV (right). The blue curves correspond to the vertical emittance corrected to 3.4 pm·rad, while the red ones to the vertical emittance blown up to 50 pm·rad. The bunch length increase at high currents in the case of the 600 kV, seems to be dominated by TBL, as the blow up of the vertical emittance does not affect the bunch length. For the higher voltage, which reduces the bunch length, a larger traverse emittance blow up is observed for the low vertical emittance, which is an indication of IBS. Figure 6 (bottom) shows the ratio of the horizontal (red) and vertical (blue) beam sizes with respect to the zero current values, for the two sets of measurements. A clear current dependent increase in both planes is observed, which gets larger if the bunch length is shorter (left plot). This is an other indication of IBS. A TBL model is necessary for comparison and benchmark of the theoretical models and the tracking codes with the data.

It is interesting to notice that, in the vertical plane, at high currents, the vertical beam size blow up is much larger than expected from the IBS predictions, even for the nominal longitudinal parameters. This may come from coupling change with current due to orbit offsets for impedance kicks and is currently under study.

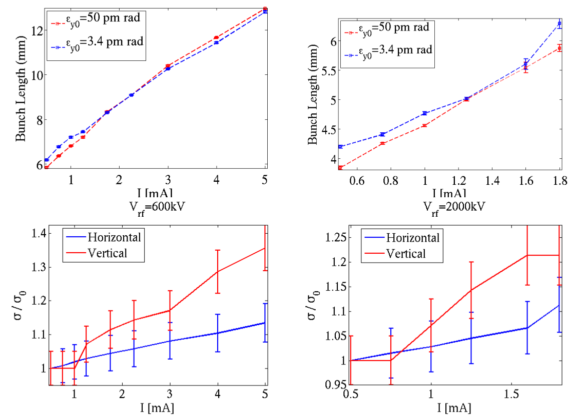

Figure 6: Left: Bunch length (top) and transverse beam size (bottom) data versus current for RF voltages of 600kV (left) and 2000kV (right).

CONCLUSION AND OUTLOOK

The SLS storage ring, having achieved a vertical geometrical emittance of 1 pm·rad at 2.4 GeV, the availability of emittance monitoring diagnostics and the ability to run at low energies, is an ideal testbed for IBS studies. Comparison between theoretical models and multiparticle algorithms, give good agreement for IBS dominated regimes. However, the bench-marking of the theoretical models and the multiparticle algorithms with measurements is crucial, as important aspects of IBS like its impact on the damping process and the generation of non-Gaussian tails is of great interest for IBS dominated beams. First measurement results at the SLS, give an indication of IBS especially at the transverse plane. A TBL model is under development for the comparison and benchmarking of the theoretical models and the tracking codes with the measured data.

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