PARAMETER SCAN FOR THE CLIC DAMPING RINGS UNDER THE INFLUENCE OF INTRABEAM SCATTERING

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Abstract

Due to the high bunch density, the output emittances of the CLIC Damping Rings (DR) are strongly dominated by the effect of Intrabeam Scattering (IBS). In an attempt to optimize the ring design, the bench-marking of the multi-particle tracking code SIRE with the classical IBS formalisms and approximations is first considered. The scaling of the steady state emittances and IBS growth rates is also studied, with respect to several ring parameters including energy, bunch charge and wiggler characteristics.

INTRODUCTION

One of the main limitations of the CLIC damping rings (DR) is the effect of intrabeam scattering (IBS) which increases the output emittances in all three dimensions. IBS is a small angle multiple Coulomb scattering effect which depends on the lattice characteristics and the beam dimensions. In older versions of the CLIC DR lattice, the IBS effect was very strong, and it was dominating the steady state emittances. Several optimization steps were taken in order to reduce the effect. Here, an intermediate design is studied (the "Long ring" version) [1]. The multi-particle tracking code SIRE [2] is bench-marked with the classical theories for IBS and a scaling of the extracted emittances and IBS growth rates, with respect to several ring parameters including energy, bunch charge and wiggler characteristics is performed in an attempt to optimize the ring design and understand the influence of the effect on the output emittances under different conditions.

CODE BENCHMARKING WITH IBS THEORIES

The IBS theory for accelerators was first introduced by Piwinski [3] and extended by Martini [4], giving a formulation which is called the standard Piwinski method, but also in a different approach by Bjorken and Mtingwa (BM) [5]. There are also several approximations developed over the years and in particular, the high energy approximation by Bane [6], which is valid under some conditions depending on the optics of the ring and other beam characteristics. In order to have a reference point, the results of the three theories are first compared with the results of the multi-particle tracking code SIRE [2]. Growth rate and geometrical emittance calculations were performed for each point of the lattice for one turn, starting from the zero current ("equilibrium") emittance values, where the effect of IBS is

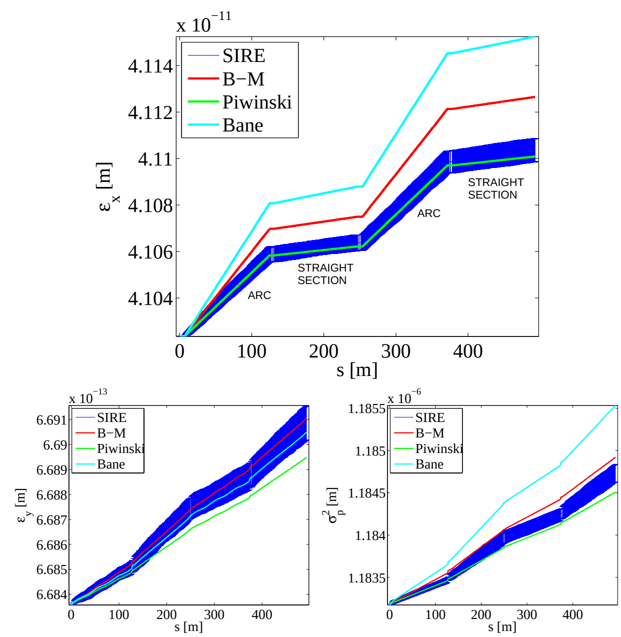

Figure 1: The one turn behavior of the horizontal emittance (top), vertical emittance (left, bottom) and energy spread (right, bottom), starting from the zero current values, as they are computed by SIRE (dark blue) and BM (red), Piwinski (green) and Bane (light blue) formalisms. In the case of SIRE, the 1σ errorbars are also shown.

strong. As SIRE is a Monte-Carlo code, the tracking simulations were performed several times and the one standard deviation error-bars are also shown in the plots of Fig.1. The three plots correspond to the behavior of the horizontal and vertical emittance and the energy spread squared, over one turn of the ring. In all three plots the results from SIRE simulations are shown in dark blue, the results from BM theory in red, the results from Piwinski theory in green and the ones from Bane approximation in light blue. The classical formalisms of Piwinski and Bjorken-Mtingwa are very close to the SIRE results with Piwinski being in perfect agreement in the horizontal plane. In the vertical plane all theories and simulations seem to be in good agreement within 2σ. For the energy spread, the SIRE results are between the BM and Piwinski theories and all the three are in very good agreement within 2σ. Bane's theory seems to overestimate the effect in the horizontal and longitudinal plane, with respect to the others. This is due to the fact that not all of Bane's approximations are valid in the case of the CLIC DR and especially the TME arc cells. However, the trend of the emittance evolution is the same. Due to this identical behavior of the theories and simulations in the arcs and straight sections of the DR, and taking into account that the simulations are quite lengthy, it is convenient to use one of the analytical approaches for understanding and minimizing the IBS effect.

PARAMETER SCAN

A scan in crucial parameters like bunch charge, energy, longitudinal emittance and wiggler characteristics was performed, using the modified Piwinski formalism. The method used to calculate the steady state, IBS dominated output emittances, is described in [7]. For this scan, the full ring optics with misalignments was used in order to create vertical dispersion which dominates the vertical equilibrium emittance. In particular, for the case of the wiggler characteristics variation, the self dispersion was kept constant, as in this region the IBS growth rates are small. In what follows, the equilibrium emittance without taking into account the effect of IBS is defined as zero current emittance and the value of the IBS dominated output emittance as steady-state emittance.

Bunch charge

Figure 2 shows the scaling of the relative difference of the steady-state and the zero-current horizontal, vertical and longitudinal emittances (top) and the steady state horizontal, vertical and longitudinal emittances (bottom) with the bunch charge (N_p). There is a power dependence for each case, i.e. $(\epsilon - \epsilon_0)/\epsilon_0 \sim (N_p)^k$, which changes for different regimes and saturates for high bunch charge. For the horizontal and vertical plane k takes values from around 2/3 to 1/2 while for the longitudinal plane from 0.6181 to 0.4178. The horizontal blow up is much larger than the vertical and longitudinal, while the later behave similarly with each other. The relative differences in the three planes scale linearly with each other.

Longitudinal emittance

The longitudinal emittance can be controlled by the RF voltage, with a lower limit set by the energy loss per turn and thus considered as a free parameter. Figure 3 shows the dependence of the relative difference of the steady state and equilibrium emittances in the horizontal and vertical planes on the relative difference in the longitudinal plane. The relative differences scale linearly with each other as was also stated in the previous paragraph.

Energy

The scaling of the relative difference of the steady state and zero current horizontal, vertical and longitudinal emittances with the energy is shown in Fig 4 (top). The dependance of the steady state emittances to the energy is shown in the bottom plots. A broad minimum is observed around

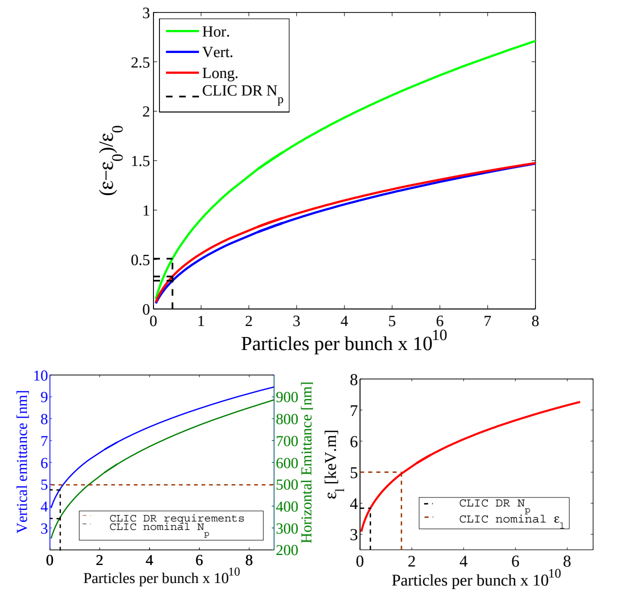

Figure 2: Scaling of the relative difference of the steady state and the equilibrium horizontal, vertical and longitudinal emittance with the bunch charge (top). The CLIC DR nominal bunch charge is indicated with dashed black lines. The dependence of the steady state emittances, horizontal and vertical (bottom, left) and longitudinal (bottom, right). The CLIC DR emittance nominal values are indicated with brown dashed lines and the nominal bunch charge with dashed black lines.

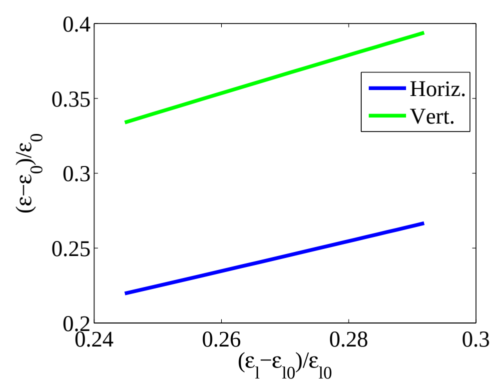

Figure 3: Dependence of emittance relative difference in the horizontal (green) and vertical (blue) plane on the relative difference in the longitudinal plane.

2.5 GeV for the horizontal and vertical emittances, where the IBS effect also becomes weaker. For higher energies, all the emittance ratios converge asymptotically to 0, as the IBS effect becomes negligible. The CLIC DR case is indicated with dashed black lines. The choice of the CLIC DR energy was driven by this behavior to be 2.86 GeV [8].

Wiggler characteristics

The dependence of the horizontal and vertical emittances on the wiggler field and period is presented in Fig. 5.

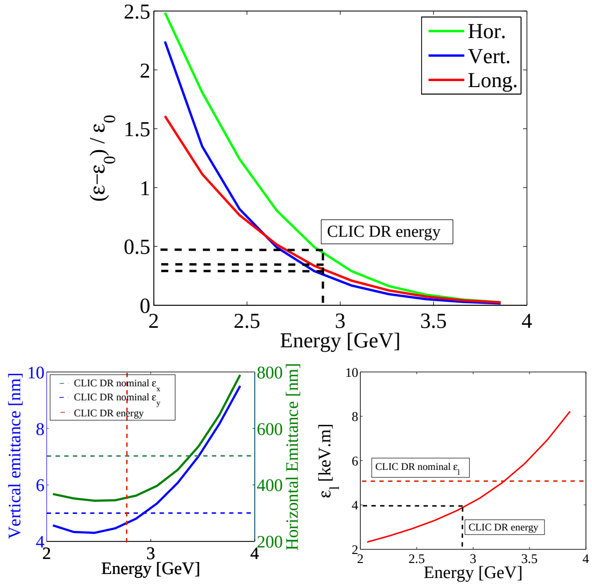

Figure 4: Relative difference of the emittances in the horizontal (blue), vertical (green) and longitudinal (red) planes with the energy (top). Steady state horizontal, vertical and longitudinal emittances on energy (bottom).

The left plot of each case shows the steady-state emittance while the right one, the ratio between the steady-state and the zero current equilibrium emittance. In all cases, the final longitudinal emittance is kept constant. The aim is to find regions where the output emittance is lower than the target one (500 nm horizontal and 5 nm vertical) but also regions where the effect of IBS is not very big. For both planes these two requirements are met, if the wiggler field is high and the wiggler period moderate. When choosing high fields and small periods, the output emittance is the lowest possible (especially for the horizontal plane) but then the effect of IBS becomes much stronger. For high field and long period, the effect of IBS becomes very small, but the horizontal emittance increases to values higher that the CLIC requirements. In the emittance ratio plots, the regions where all the emittance requirements are met are indicated with black dots. Similar results are obtained without constraining the longitudinal emittance. However, in that case, there is a region where both horizontal and vertical emittances and their ratios with the zero current values are minimized, whereas the longitudinal emittance becomes maximum.

CONCLUSION

The classical IBS theories of Piwinski and Bjorken-Mtingwa and the high energy approximation of Bane were compared with the multi-particle tracking code SIRE and the results, especially for the complete theories, are in very good agreement. The scaling of the relative difference of the steady state and the equilibrium emittances was also studied with respect to bunch charge, energy, longitudinal emittance and wiggler characteristics. All three relative differences scale with a power of N_p, which changes for different regimes. The three relative differences scale linearly with each other. Another interesting result is that the high wiggler field and a moderate wiggler period can provide low enough steady-state emittances but also weak IBS effect.

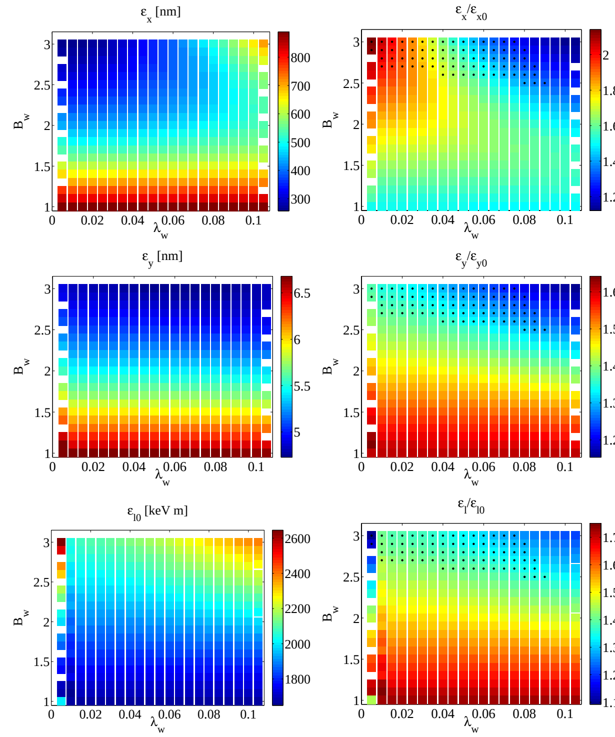

Figure 5: Scaling of the extracted emittances with the wiggle field and period. In the left plots the extracted emittances are shown, while in the right ones the ratio between the extracted and the zero current emittances. The black dots indicate solutions where all the emittance requirements are met. The longitudinal emittance is kept constant.

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