Simulations and Studies of Electron Beam Dynamics under Compton Back-scattering for the Compact X-ray Source ThomX

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SIMULATIONS AND STUDIES OF ELECTRON BEAM DYNAMICS UNDER COMPTON BACK-SCATTERING FOR THE COMPACT X-RAY SOURCE ThomX*

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Abstract

In this article are presented beam dynamics investigations of a relativistic electron bunch in the compact storage ring ThomX (50 MeV), which is under construction at LAL to produce hard X-ray using Compton Back-Scattering (CBS). The effect of CBS has been implemented in a 6D tracking code. In addition to CBS, the influence of lattice non linearities and various collective effects on the flux of scattered Compton photons is investigated.

INTRODUCTION

ThomX [1] is a project of a compact high flux X-ray source based on the Compton scattering of laser photons and relativistic electrons. A 50 MeV electron bunch is injected in the storage ring with circumference 16.8 m where it collides with laser pulses in a Fabry Perot optical cavity on each turn. The beam storage time is around 400000 turns, corresponding to $20ms$. The ThomX layout is presented on figure 1.

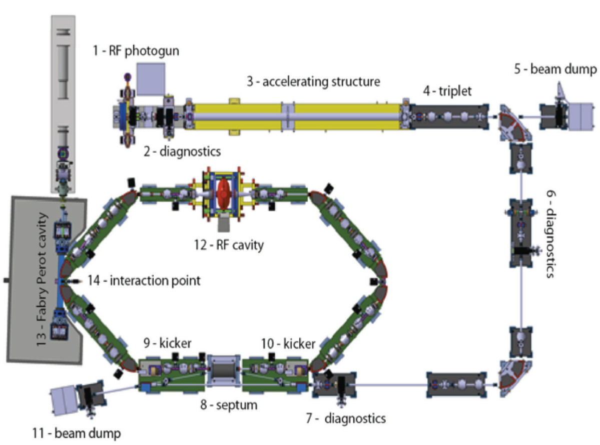

Figure 1: ThomX source layout.

ThomX is a low energy storage ring with a relatively high charge (1 nC per bunch) beam for a small accelerator. Therefore the collective effects may have a large influence on beam dynamics. It is then important to predict the beam dynamics of the electrons and the degradation of the X-ray flux of the scattered beam quality and the electron beam due to:

- Linear and non linear beam 6D tracking
- Collective effect
  - Resistive wall (RW) [2]
  - Longitudinal Space Charge (LSC) [3]
  - Coherent Synchrotron Radiations (CSR) [4]
- Compton Back Scattering (CBS) Random effect on the electron beam energy

To achieve this task a beam tracking code has been developed on MATLAB 2010a [5] in which the code CAIN [6] has been also implemented as routine to the 6D tracking code to simulate CBS interaction effect on the electron beam and to estimate the degradation of scattered photon flux due to collective effects. This code allows full 6D tracking over a long number of turns and can be run on computing farms, for example to simulate a full ThomX injection/extraction cycle

COMPUTER SIMULATION

Series of simulations were made to investigate which of the collective effects will have the biggest influence on the beam dynamics and as a consequence on the flux of scattered Compton photons. To achieve this task was made series of simulations including non linear beam 6D tracking with CBS and add one by one RW, LSC and CSR effects.

This simulation were made over 150000 turns that correspond to 8.4 ms and for initial charge of electrons bunch 1 nC. Result for this simulations are presented on fig. 2.

As we can see the influence of RW and LSC either taken separately or together is negligible compared to the influence of CSR. The injected bunch from the linac, having a short duration (~ 4 ps rms), suffers from very strong CSR effect over the first turns before lengthening.

The reason for this decrease of flux ($blue$ line: LD CBS CSR not split at fig. 2) is that due to the CSR wake field the electron bunch position and phase amplitude increase. Also it increases the longitudinal size of the bunch (see fig. 3 and fig. 4).

We also noticed that for such initial charge of 1 nC, the electron bunch can be splitted in the longitudinal plane due to the effect of CSR wake field. This splitting leads to large amplitude oscillations of the barycentre of the bunch that leads to the losses of $\sim$ 50% of electrons in the bunch. We can see that this oscillations as the bump on fig. 5, 6 at around 1.1 ms. The splitted bunch increases so much that one of the splitted parts goes out of acceptance. Flux for this situation is presented by red color (LD CBS CSR split) on fig 2.

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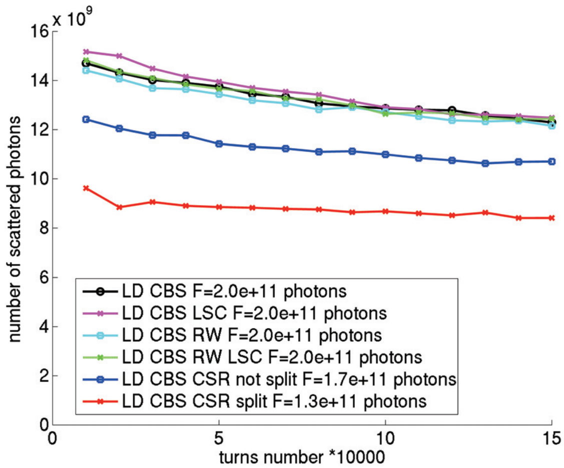

Figure 2: Comparing influence of different effects on Compton backscattering flux. In the case of the CSR simulations, 97% of the particle survived in the non split case and 50% survived in the split case. F is the total flux integrated over one injection cycle 150000 turns.

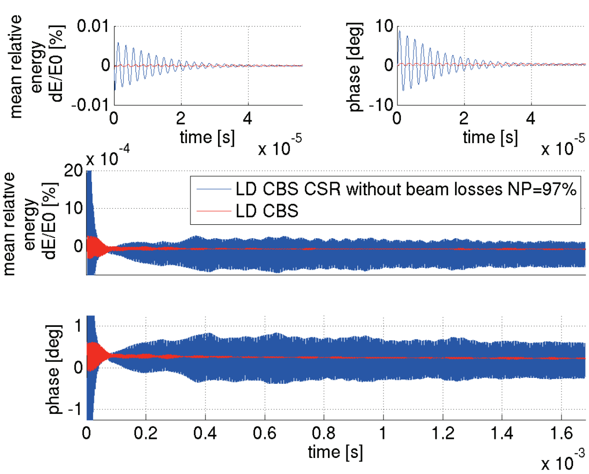

Figure 3: Oscillations of mean relative energy spread (middle) and phase (bottom) of the electron bunch over the total duration of the injection and zoom over the first 50 μs (top) with simulation effect of CSR wake field with simulations made without collective effect. NP is number of remaining macroparticle in %.

The only one difference between these two simulations of CSR it is the seed of the (pseudo) random number generator to create the distribution of the injected the bunch of electrons. On fig. 7 is presented the evolution of longitudinal phase space for this two particular cases.

Here it is important to remind that CSR wake field has the linear dependence from the initial beam charge and simulations with the initial charge of 1.1 nC shows that influence of CSR wake field will destroy the electron beam in the same way like as it is shown on fig. 5, 6. Also this destructive effect is not observed for an initial charge of

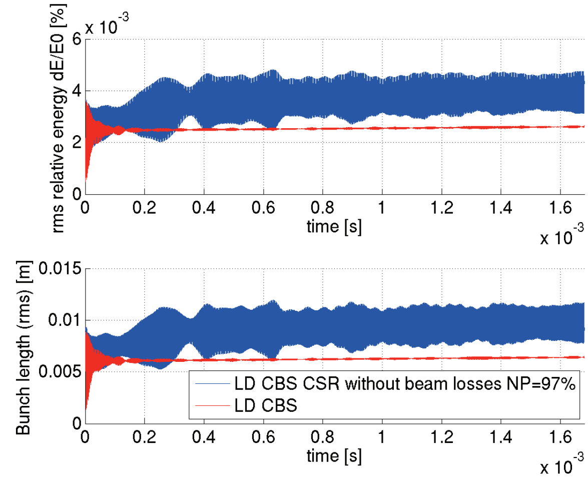

Figure 4: Oscillations of rms relative energy spread and longitudinal bunch length of the electron beam with simulation effect of CSR wake field with simulations made without collective effect.

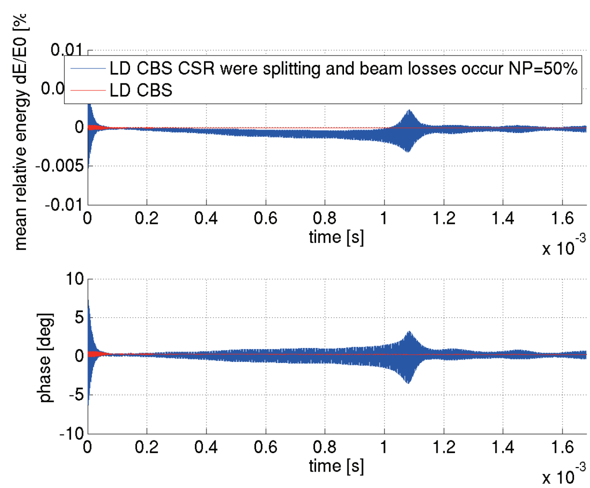

Figure 5: Oscillations of mean relative energy spread and phase of the electron beam in case of destructive effect of CSR wake field with simulations made without collective effect. The bump around $1.1ms$ is described in the text on page 1.

the bunch of 0.9 nC and smaller. So we can conclude that the initial charge at 1 nC is the critical charge threshold for destructive effects of CSR. To show this an additional set of simulations to see how effect of CSR depends from initial charge of the injected bunch was made. That simulations was made for range of 0.7, 0.8, 09, 1, 1.1 nC and each of them was repeated 10 times for different seed of the (pseudo) random number generator to create the distribution of the injected the bunch of electrons. Result of this simulations presented at fig.8, 9.

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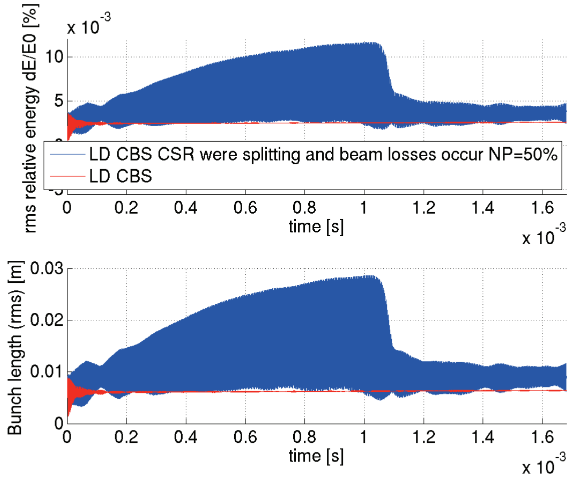

Figure 6: Oscillations of rms relative energy spread and longitudinal bunch length of the electron beam in case of destructive effect of CSR wake field with simulations made without collective effect.

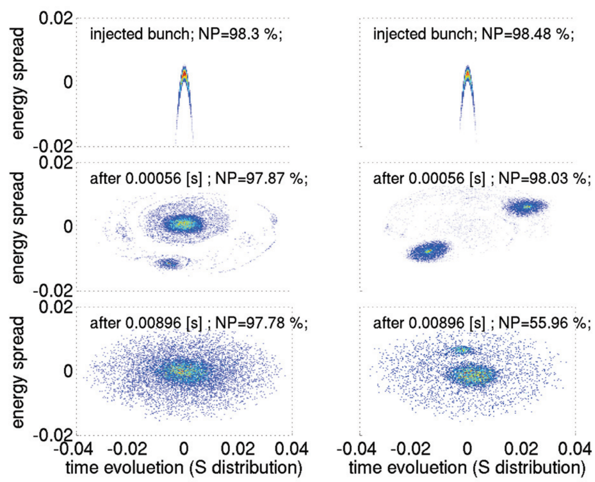

Figure 7: Evolutions of longitudinal phasespace. Left is for CSR without splinting and losses. Right is for CSR with split bunch that provide to $\sim 50\%$ losses of particle.

CONCLUSION

In this work we show the influence of collective effects on beam dynamics in the ThomX electron storage ring and their impact on flux of Compton scattered photons. The largest impact is the effect of Coherent Synchrotron Radiations (CSR) in the first turns. It has destructive effect and it increases the amplitude of oscillations and grows energy spread and longitudinal length of the bunch. To prevent this negative impact of CSR there are two possibilities. One of them is to reduce the initial charge of the injected beam. But it will also reduce flux. Another way is to operate the injection with different setting as: an energy offset to compensate the first turn CSR losses and running the linac slightly off-crest in order to fix the bunch lengthening and

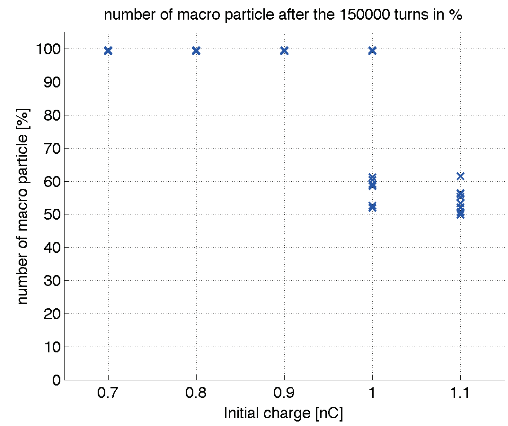

Figure 8: Dependence of final number of macroparticles from initial charge of the injected bunch.

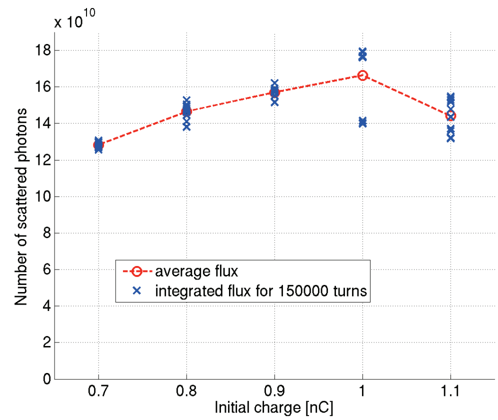

Figure 9: The number of Compton scattered photons for different initial charge of the injected bunch.

to escape from CSR risks. Last method gives us the possibility to damp the amplitude of oscillations and to relax destructive effect of CSR.

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