ASSESSMENT OF CERN PSB PERFORMANCE WITH LINAC4 BY SIMULATIONS OF BEAMS WITH STRONG DIRECT SPACE CHARGE EFFECTS

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Abstract

The performance of the CERN PS Booster (PSB) synchrotron is believed to be limited mainly by direct space charge effects at low energy. The main motivation to construct Linac4 is to raise the PSB injection energy to mitigate direct space charge effects. At present, simulation of the injection and the low energy part of the cycle aim at defining Investigations on the influence of parameters of the injected beam on the performance of the PSB are described.

INTRODUCTION

The main motivation for Linac4 [1,2], a linear accelerator for H^- presently under construction, is to raise the injection energy into the CERN PS Booster from at present 50 MeV to 160 MeV in order to mitigate direct space charge effects. At the same time, the present conventional multiturn injection into the Booster will be replaced by an H^- charge exchange injection. This relaxes constraints on beam brightness and, in particular, beam intensity required from Linac4 and, together with the 3 MeV chopper, allows for implementing painting procedures to shape beam distributions suitable for the generation of high intensity and brightness beams.

However, the new H^- charge exchange injection has to be within the fixed lattice of the existing Booster [3]. In particular, the so-called chicane, i.e. an orbit bump consisting out of four magnets has to be installed in the existing straight section. These dipole magnets must be short and thus introduce additional focusing perturbing the lattice [4].

The simulations presented in this report focus on simulations of the impact of strategies to cope with lattice perturbations, introduced by the injection chicane, on beam dynamics and Booster performance. In particular, the question, whether the vertical injection tune above a half-integer resonance, mandatory at present for best performance with high brightness and high intensity beams, can be kept with Linac4, is addressed.

HANDLING LATTICE PERTURBATIONS

Fig. 1 shows a sketch of the H^- charge exchange straight section [3,4]. Two closed orbit bumps are superimposed. The so-called chicane, a closed orbit bump consisting out of four BS magnets serves to merge the incoming H^- beam with the circulating proton beam. To satisfy geometric constraints, short magnets with a deflection of 66 mrad are required and introduce additional focusing. In case of rectangular magnets, the additional focusing is in the vertical plane and induces strong betatron beating since the vertical tune for high intensity and brightness beams is close to a half-integer resonance. Whereas the injection chicane falls (linear fall assumed for the simulations presented) after completion of the injection, the painting bump falls during injection to move the injected particles away from the injection foil.

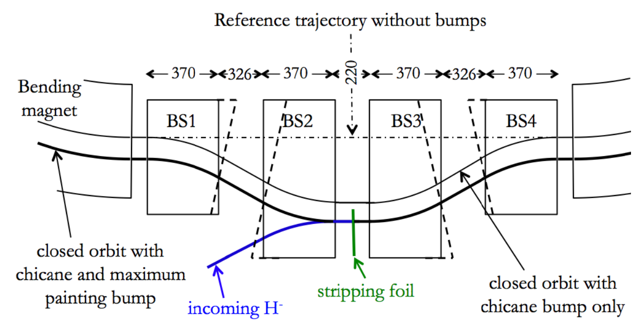

Figure 1: Sketch of the H^- charge exchange injection section

The BS magnets have been made as long as possible within the given Booster lattice and two schemes to reduce these perturbations [4] have been proposed and simulated:

- Passive Compensation:
  Vertical focusing added by the chicane dipoles can be reduced by rotating the pole faces as indicated in Fig. 1 and assumed for simulations presented. In practice, the same effect would be obtained by adding gradients to the BS dipole fields. The effect of the focusing added in the horizontal plane is smaller since, the tune is not close to a half-integer resonance. With passive compensation, the chicane fall time can be short and is 0.5 ms
- Active Compensation:
  Vertical betatron beating induced by the chicane can as well be compensated by additional quadrupolar components at appropriate phases outside the injection section. Additional trims on two defocusing lattice quadrupoles at a betatron phase of about $\pm 0.72\,\pi$ from the perturbations decreasing, for a linear chicane fall, following a parabola have been assumed. The effect of the additional perturbations is small, because the horizontal betatron function at the location of the compensation is small. Since the additional quadrupole trims have to follow pre-programmed time evolution a longer chicane fall time of 5 ms is been assumed.

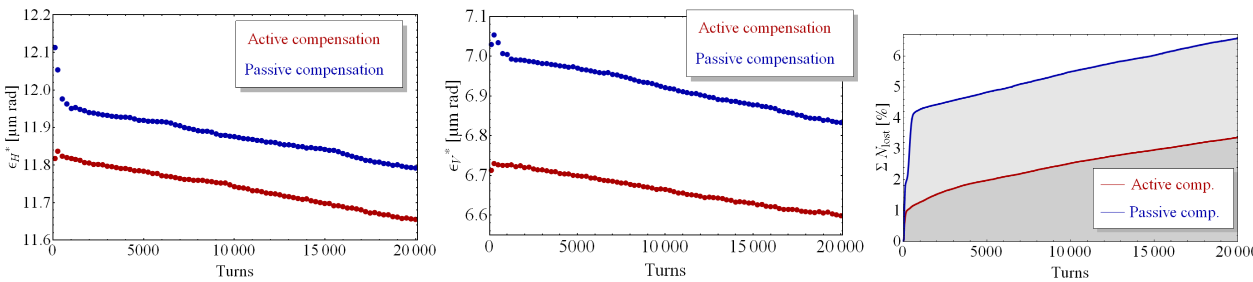

Figure 2: Comparative simulations of active (red traces) and passive (blue traces) compensation of the chicane for high intensity beams. The left and central images show the time evolution the horizontal and vertical normalized emittance, respectively. The right image shows the accumulated losses.

SIMULATIONS

All simulations presented have been carried out with ORBIT [5], a code written to simulate H^- charge exchange injection and beam dynamics with direct space charge effects. Transverse space charge effects are estimated with the so-called 2.5D approach.

The lattice properties evolve with time during the fall of the chicane. Thus, a special procedure, making use of an undocumented feature of ORBIT allowing redefining magnet parameters, has been used to implement this time dependence of the lattice. The chicane BS magnets have been modelled as bending magnets (and not thin elements as the weaker dipoles generating the painting bump) in order to properly simulate their impact on the lattice. As a consequence the reference trajectory in the injection section evolves during the fall of the chicane and the positions of fixed apertures defined w.r.t. this reference trajectory changes with time as well.

To simulate as realistically as possible the envisaged painting scheme and, in particular, the complex energy modulation and chopping scheme [6], initial macro-particle distributions at injection are generated in a dedicated program and provided on files for ORBIT runs.

Apertures have been implemented around the Booster at locations where losses are expected to occur. A 300 μg/cm^2 C foil has been included* to take transverse blow-up due to multiple scattering into account.

All simulations have been carried with 500 000 macro-particles and have been running on around 20 cores.

RESULTS

High Intensity Beams

Simulations for both active and passive compensation were carried out for the injection, followed by the fall of the chicane and up to 20 ms assuming 1.6 10^{13}. The painting bump fall time and the initial offset between the injected beam and the closed orbit with bumps were adjusted to obtain normalized rms emittances of ε^*_x=12 μm rad and ε^*_y = 7 μm rad. For passive compensation, only best results obtained with a large pole-face rotation

*Now, the foil thickness is expected to be about 150 to 200 μg/cm2 and, thus, multiple scattering has been overestimated in the simulations.

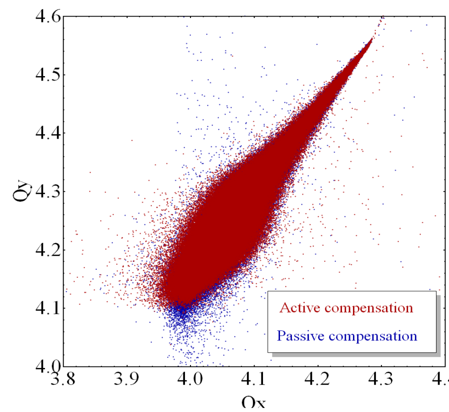

Figure 3: Tune footprint after 20 ms for the simulation of a high intensity beam.

angle of 64 mrad (i.e. the BS magnets are almost sector bend during injection) are presented.

The evolutions of the normalized rms emittances and of the accumulated losses are shown in Fig. 2. The normalized emittances decrease with time; this can only be explained by a reduction of phase space density close to the boarder of the acceptance due to blow-up and losses. Most losses take place during injection and chicane fall; Losses are reduced significantly with active compensation. Note that simulations with imperfect active compensation setting the additional quadrupolar components to the 90% and 110% of their nominal values yielded only slightly increased losses.

The tune foot prints shown in Fig. 3 are similar for both cases with tune spreads up to about 0.5 at low energy.

LHC type high brightness beams

The LHC nominal beam intensity is 3.25×10^{12} protons per PSB ring at 1.4 GeV extraction (2 bunches per ring) assuming lossy transmission to LHC. The full intensity is injected in 20 machine turns; the required normalized beam emittances at PSB extraction are $\varepsilon^*_{x,y}$ = 2.5 μm rad, which are obtained by adjusting the painting bump fall time and a vertical offset of the arriving beam. For simulations with passive compensation, the pole face rotation angle of 64 mrad is used for the passive compensation. Fig. 4 shows the emittance evolutions along with the accumulated losses. Losses, shown in addition as well in Fig. 5, are, as expected, smaller than for high intensity beams. With passive compensation,

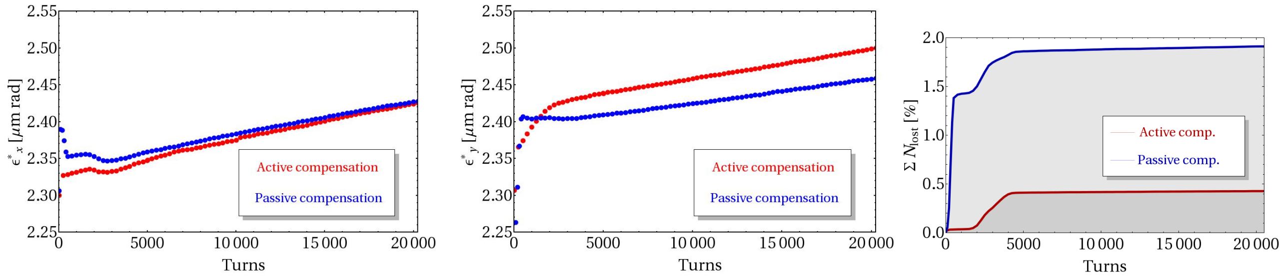

Figure 4: Comparative simulations of active (red traces) and passive (blue traces) compensation of the chicane for LHC type beams. The left and central images show the time evolution the horizontal and vertical normalized emittance, respectively. The right image shows the accumulated losses.

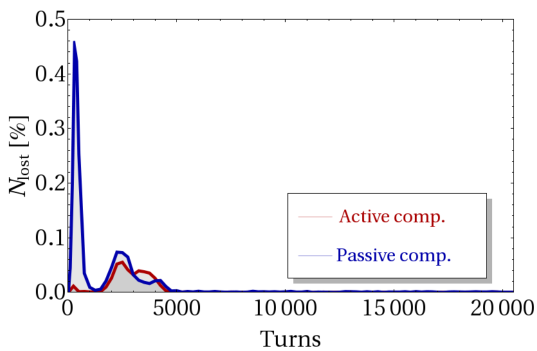

Figure 5: Instantaneous losses during the simulation up to 20 ms for a simulation of LHC beams.

losses occur mainly at the beginning of the simulation until completion of the chicane fall. Further losses around turn 4000 (present as well for high intensity beams, but less visible due to the higher loss rates in general) for both passive and active compensations, are caused by particles not captured into the RF bucket then drifting towards an aperture restriction.

Fig. 6 shows emittance evolutions for a longer duration of about 100 ms corresponding to acceleration up to 317 MeV. Surprisingly, the blow-up rates do not decrease significantly due to the increase in beam rigidity. It is not clear to which extent this may be caused by numerical artefacts, e.g. due to an insufficient number of macro-particles or the vertical tune, which is not lowered as programmed for the real machine.

CONCLUSIONS AND OUTLOOK

Performance expected from the CERN PS Booster with Linac4 under different assumptions to deal with perturbations introduced by the injection chicane, required for the H^- charge exchange injection, have been assessed by simulations. Loss rates and emittance blow-up rates around injection and fall of the chicane are significantly larger than the ones later without perturbations. These observations indicate that loss and blow-up rates around injection and chicane fall are dominated by effects to be expected in the real machine.

With both compensation schemes and for both high intensity and high brightness LHC type beams, acceptable loss and blow-up rates are obtained with an injection working point just above a half-integer resonance. Losses

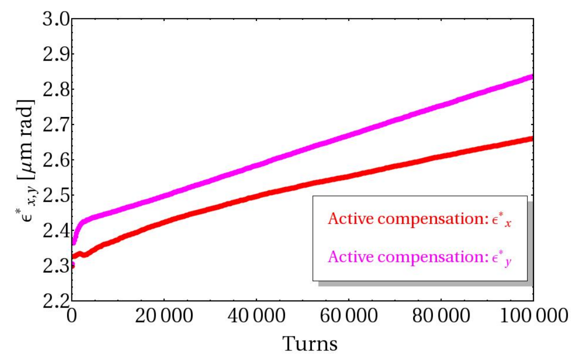

Figure 6: Evolution of the transverse rms emittances up to about 100 ms (i.e. 317 MeV) for LHC beams simulation.

with active compensation, even with imperfect setting of the compensation, are significantly lower than the ones with passive compensation.

Next steps are the introduction of imperfections, both caused by multipolar components created by the new hardware to be installed and machine imperfections and, injection matching and painting optimizations.

ACKNOWLEDGEMENTS

We would like to thank, S. Cousinau and J. Holmes for help and many discussions on the use of ORBIT.

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