LATTICE ISSUES OF THE CERN PSB WITH H^- CHARGE EXCHANGE INJECTION HARDWARE

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Abstract

The motivation for the construction of CERN Linac4 is to improve the performance of the PSB by raising the injection energy and implementing a new H^- charge exchange multiturn injection scheme. Lattice perturbations introduced by the new injection hardware are described. Strategies to mitigate the consequences, first by minimizing the additional focusing introduced and, by compensating the residual perturbation, are reported.

INTRODUCTION

Linac4 [1,2] is a linear accelerator constructed at present at CERN to replace the ageing Linac2. Linac4 will provide H^- ions with 160 MeV to the CERN PS Booster (PSB). The main motivation is to increase the PSB injection energy from at present 50 MeV with Linac2 to mitigate direct space charge effects and increase the maximum beam brightness and intensity available from the PSB by about a factor 2. At the same time, the conventional multiturn injection of the Linac2 proton beam, with betatron stacking in horizontal phase space, is replaced by an H^- charge exchange injection [3,4].

The PSB has a very regular lattice made of 16 identical symmetric periods and with triplet FDF focusing. The H^- charge injection has to be implemented within the existing machine and all hardware, except the injection painting bumpers, will be installed in one straight section.

Inacceptable perturbations of the lattice, in particular in the vertical plane, induced by the additional injection hardware (asymmetric so-called chicane) of the initial proposal [3] are described. In a first step, the perturbations are reduced by installing longer magnets to create the "chicane" orbit bump and by reducing the deflection angles. Furthermore a "passive" compensation scheme bringing a part of the perturbation into the horizontal plane and an "active" compensation with additional quadrupolar (trims on main quadrupoles) field components are described.

OPTICS PERTURBATIONS DUE TO THE INJECTION CHICANE

The incoming H^- beam and the circulating proton beam are brought close to each other with a simple dipole magnet, replacing the injection septum of a conventional injection. In principle, a main lattice magnet could be used for that purpose. However, due to the constraint that the H^- charge exchange injection has to be implemented in the existing PSB, a so-called chicane is added to the lattice in the injection section. The chicane is made out of four dipoles, named BS: the first magnet BS1 acts only on the circulating proton beam and the second BS2 magnet serves to merge the injected H^- beam with the circulating proton beam. Due to the restricted space, and to maximise the clearance between the H^o/H^- dump and the circulating beam, an asymmetric chicane with strong (providing up to 90 mrad deflection) and short (250 mm magnetic length) rectangular BS magnets was foreseen initially. The vertical focusing generated together with the vertical tune close to the half-integer resonance (at present with Linac2, the vertical tune at injection of high intensity beams is even above the half-integer resonance) to generate space for the large direct space charge tune spread with high intensity, induces strong vertical beta-beating plotted in Fig. 1 for $Q_v = 4.47$.

Optics perturbations due to H^- injection hardware are a limitation as well for the FNAL Booster [5].

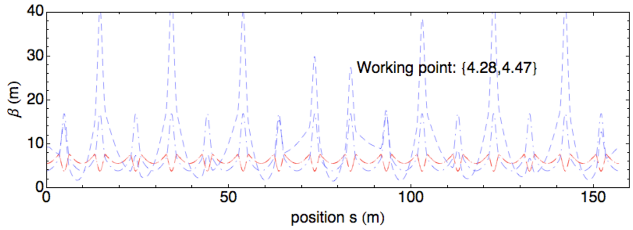

Figure 1: Betatron functions of the lattice with the initially planned injection chicane (solid lines) compared to a lattice without perturbations (dot-dashed). Red and blue lines are for horizontal and vertical betatron functions, respectively.

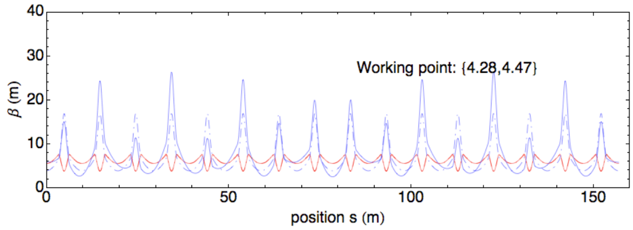

Figure 2: Betatron functions after reducing the perturbation by increasing the BS magnetic length and decreasing the deflection.

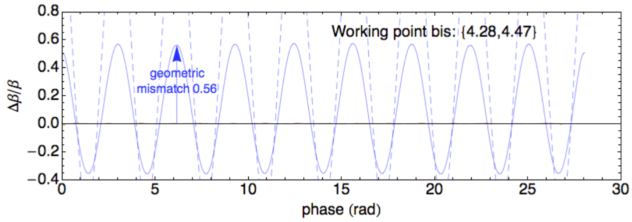

Figure 3: Beta-beating with the initial injection chicane (dashed) and after increasing the magnetic length and decreasing the deflection angles.

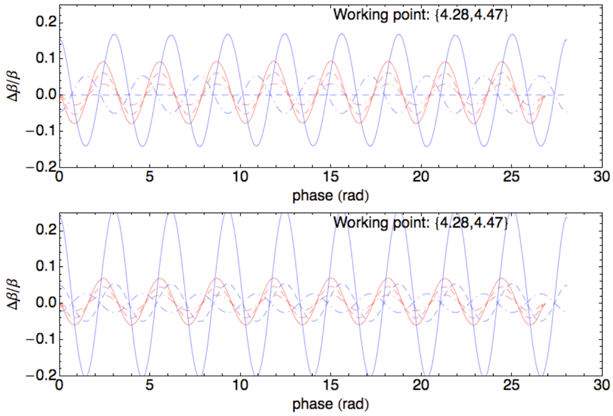

Figure 4: Beta-beating with passive compensation of perturbations due to the chicane by rotating BS pole faces by 44 mrad (upper image) and 33 mrad (lower image) for three different deflections 66 mrad (solid), 44 mrad (dashed) and 22 mrad (dot-dashed)

MEASURES TO MITIGATE LATTICE PERTURBATIONS

Long Dipoles with Small Deflections

A first measure to reduce perturbations due to the chicane is to increase the magnetic length of the BS dipoles to the maximum ~370 mm possible within the tight space constraints and to decrease the deflection angles to 66 ±mrad for all four BS dipoles. Resulting betatron functions are shown in Fig. 2. Beta-beating with the initial geometry and the one with longer and weaker BS dipoles is plotted in Fig. 3 and shows that the geometric mismatch factor is reduced to 0.56.

Passive Compensation with Additional (De)Focusing Close to the Perturbation

Lattice perturbations induced by the injection chicane can be further reduced by transferring a part of the perturbation from the vertical phase space to the horizontal one by adding quadrupolar field components. Since the horizontal tune is not close to a half-integer resonance (and the horizontal betatron function is similar to or smaller than the vertical one), the horizontal beta-beating induced tends to be smaller than the vertical one.

In case of a “passive” compensation, these quadrupolar components are generated close to the source of the perturbation by partially rotating pole-faces of the BS magnets or adding quadrupolar field components, both giving very similar results in terms of residual beta-beating. The results shown are obtained with rotated BS magnet pole-faces. However, for simplicity of the construction, quadrupolar components added to the profile are preferred for a practical implementation. Since during the ramp down of the chicane, after completion of the injection, the deflection angles evolve with time, a compromise for the compensation has to be found. Fig. 4 shows the effect of rotated pole-faces on beta-beating with three different deflection angles of the BS magnets during injection and during the fall of the chicane. Geometric mismatch factors as a function of the BS deflection angle are plotted in Fig. 5 for two different cases. When the deflection is equal to the pole-face rotation angle, the BS magnets become sector bends and all vertical perturbation, and thus vertical mismatch, vanishes.

With passive compensation, the closure of the injection chicane cannot be perfect during the fall. Evaluations have shown that the residual orbit perturbations are small and acceptable.

Passive compensation of the perturbation due to the chicane do not require to change any quadrupole current provided variations of the tune in the order of 0.01 are acceptable. Thus, limited power supply response times of power converters do not imply any restriction on the chicane fall time, which, thus, may be short in this case.

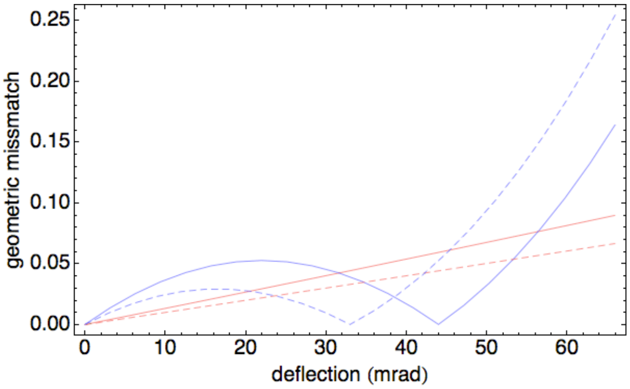

Figure 5: Geometric mismatch in the horizontal (red) and vertical (blue) phase space as function of the deflection during the fall of the chicane.

Active Compensation with Additional Quadrupolar Fields

Lattice perturbations due to the chicane magnets can as well be compensated by freely programmable additional quadrupolar components. Additional quadrupoles in the injection section straight section have been disregarded due to space constraints. Trim power supplies on two defocusing lattice quadrupoles are efficient for compensation:

- Large vertical and small horizontal betatron functions at the location of the defocusing quadrupoles allow an efficient compensation with small perturbations in the horizontal plane.
- The defocusing quadrupoles of the triplets adjacent to the injection are located at a phase of ~±50^o from the perturbation, which is not appropriate for compensating. However defocusing quadrupoles in sections 3 and 14, located two and a half periods upstream and downstream from the perturbation are appropriate for compensation.

Comparative plots without and with “active” compensation are shown in Fig. 6. Outside the region comprising the perturbation and the quadrupoles with trims for compensation, the residual beta-beating is

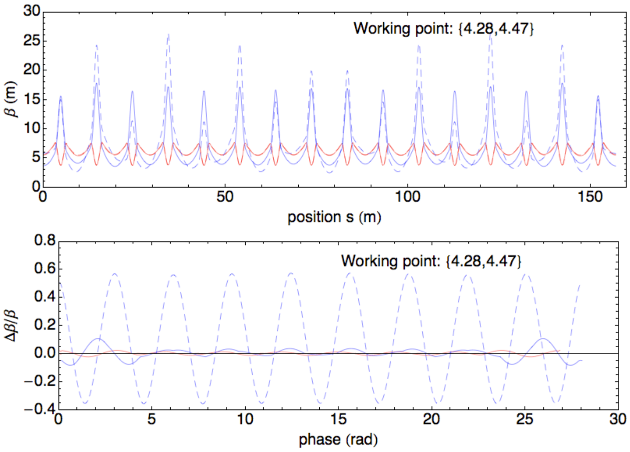

Figure 6: Betatron functions (upper image) and beta-beating (lower image) with (solid) and without (dashed) active compensation of the perturbations introduced by the injection chicane. Red and blue traces denote horizontal and vertical phase space.

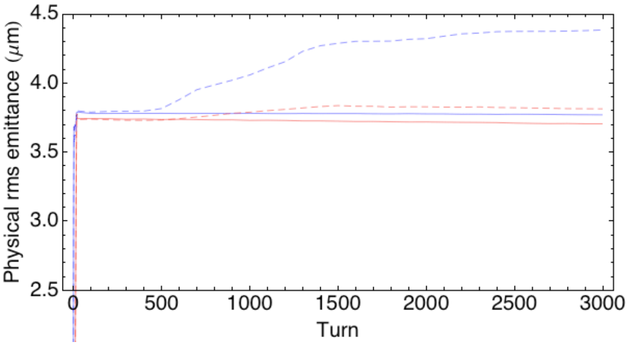

Figure 7: Evolution of rms emittances from ORBIT [6] simulations without and with active compensation.

negligible. Within this region, there is some residual perturbation in the vertical plane, but which does not depend significantly on the vertical tune.

Active compensation is significantly more complex and requires changing quadrupole currents (trims and, possibly, main quadrupole currents as well to keep the working point fixed) within the fall of the chicane, which, thus, has to last at least several milliseconds. On the other, the residual lattice perturbation can, in principle, be corrected for working points very close to the half-integer resonance and during the whole fall of the chicane.

Results of Comparative Simulations

First comparative simulations of beam dynamics with strong direct space charge forces of a lattice without compensation and with 'active' compensation of the injection chicane have been carried out with the code ORBIT [6]. A LHC type beam is been injected with painting during 20 turns and tracked over 3000 turns corresponding to about 3 ms. For these simulations, the evolution of the lattice during the fall of the chicane has not been simulated, but the lattice stayed constant. Evolution of the rms emittances are plotted in Fig. 7. One notes that the emittance blow-up is reduced significantly, in particular in the vertical plane.

SUMMARY AND OUTLOOK

Perturbations of the lattice induced by the chicane needed for the H$^-$ charge exchange injection together with strategies for compensation have been presented. First comparative simulations of beam dynamics with strong space charge forces indicate that the compensation reduce significantly the transverse emittance blow-up.

Passive compensation does not allow for a perfect compensation during the whole fall of the chicane, but a compromise must be implemented. On the other hand, the fall of the chicane may be fast and, thus, the beam experiences the perturbation during a short duration only. A fast fall of the chicane is more costly and delicate for eddy currents effects (and may require magnets inside the vacuum), but has the advantage to contribute to retract the circulating beam quickly from the injection foil.

Active compensation requires quadrupole (trim) currents to vary during the fall of the chicane, which must be sufficiently slow. Thus, the beam will experience perturbation with a better compensation, but for a longer duration. A cheaper slower chicane has the disadvantage that it is more difficult to make sure that the injection foil cannot be damaged by circulating beam. With an active compensation, one could, in principle, keep the very high vertical tune above the half-integer resonance for the injection of very high intensity beams.

Further simulations of beam dynamics with strong space charge forces, modelling the time dependant lattice during the fall of the chicane will be carried out to better quantify the effectiveness of the compensations and compare the two compensation schemes proposed.

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