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PAINTING SCHEMES FOR CERN PS BOOSTER H- INJECTION

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Abstract

The present 50-MeV proton injection into the PS Booster will be replaced by a H^- charge exchange injection at 160 MeV to be provided by Linac4. The higher energy will allow producing beams at higher brightness. A set of kicker magnets (KSW) will move the beam across the stripping foil to perform phase space painting in the horizontal plane to reduce space charge effects. The PSB must satisfy the different users with very different beams in terms of emittance and intensity. Therefore, the KSW waveforms must be adapted for each case to meet the beam characteristics while minimizing beam losses. Here we present the results of the simulations performed to optimise the injection system. A detailed analysis of the different painting schemes is discussed, including the effect of the working point on the painted beam, and variations in the offset of the injected beam.

INTRODUCTION

In this paper we present a description of the injection process and its influence on the profile for different beams. We assume that each pulse coming from the Linac4 and reaching the 4 rings of the PSB has 6.5x10^{13} protons over a length of 400 μs with an average current of 26 mA. The number of injection turns needed for each PSB user is adjusted according to the required intensity, taking into account that the revolution period of the PSB at injection is $\sim 1\mu s$. We will describe the injection for two particular cases: LHC beam and High Intensity beam (HI). In the latter case, an injection over 100 turns has been considered, in order to build up a final intensity of 1.6×10^{13} p^+. This means injecting in the PSB twice as much intensity as we do today for this kind of beam. with twice as much intensity. Also the beam brightness of the LHC beams would be doubled. Two scenarios have been analyzed for the simulations. We have called tune 1 the baseline working point, with tunes Q_x=4.28 and Q_y=4.55. The second scenario, called tune 2, is intended to reduce space-charge blow up during acceleration and corresponds to a working point of Q_x=4.43 and Q_y=4.60.

Table 1 summarizes the beam characteristics of the two different LIU [1] beams studied in this paper and compares it with the present values in operation.

Table 1: Characteristics of LHC and HI Beams (Present and LIU). Injection Energy, Extraction Energy, Beam Intensity per Ring and Normalized Emittance (Horizontal and Vertical)

	Present		LIU	
Beam	LHC	HI	LHC	HI
E_{inj} [MeV]	50	50	160	160
E_{ext} [GeV]	1.4	1.4	2.0	1.4
N [$x10^{12}$]	1.8	8.0	3.4	16
$\epsilon_{N,x}[\mu m]$	2.1	15	1.7	13
$\epsilon_{N,y}[\mu m]$	2.1	8	1.7	6

SIMULATIONS

We simulated the H^- charge exchange process with the ORBIT code [2]. The stripping foil is made of Carbon with a density of 200 $\mu g/cm^3$ and a dimension of 32 mm [H] and 58 mm [V]. The simulations include a complete aperture model that allows to analyze the particle losses around the PSB ring. We have assumed a matched (including dispersion) 0.4 μm normalized emittance beam and we have injected in each case a total of 5×10^5 macroparticles. The space-charge effects have been taken into account as well as the edge focusing of the chicane magnets. For the case of HI beams, we have simulated also a phase space painting in the longitudinal plane.

LHC BEAMS

Other studies have been carried out to define the optimal brightness in the PSB, characterizing a relation (curve) between beam intensity and target emittance [3]. We have studied how the H^- injection is able to reproduce each point of the so-mentioned curve. For this purpose we have assumed a maximum intensity of 3.4×10^{12} p^+. For this beam intensity we need to inject over 21 turns.

To enlarge the emittance of $\epsilon_N = 0.4\mu m$ provided by Linac4, the injected beam is off-centered with respect to the circulating one. For the vertical plane, the offset is applied using the steerers in the transfer line. For the horizontal one, we have varied instead the circulating orbit with respect to the injected beam (which is located at $x = -35$ mm) with the help of the KSW magnets. We have observed that for the same initial conditions, different tunes give different final emittances, as the particle distribution turns by a different angle in the respective phase space. For this reason the position of the circulating beam at the stripping foil must be adjusted for each tune. We have placed the KSW bump at $x = -31.5$ mm for tune 1 and $x = -33.5$ mm for tune 2. The vertical offset of 3 mm gives similar results as the tune difference in this case is very small (~ 0.05). Assuming an ideal machine, we have attained for both working points the target emittances at the end of injection of $\sim 1.2\mu m$; that would leave some margin ($\sim 0.5\mu m$) for other sources of emittance growth such as optics mismatch or blow up from space charge during acceleration [4].

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HIGH INTENSITY BEAMS

A special case is represented by the ISOLDE beams. As from Table 1, we have studied the injection of a beam with a factor two higher intensity with respect to the present one. A total of 100 turns are needed to achieve such a high intensity in the ring.

Studies were done to reach the maximum possible emittance compatible with an acceptable percentage of losses at injection. The painting bump takes place in the horizontal plane only, and the vertical emittance is enlarged (as for the LHC beams) by injecting with a vertical offset.

Figure 1 shows the amplitude of the painting bump for both tunes and compares it with the respective average position of the beam. This position ideally follows the KSW bump. We observe a difference for the first 10 turns. This difference is due to a non zero average $\Delta p/p$ of the injected beam (due to the longitudinal painting) and to the value of the horizontal dispersion at the injection point ($D_x = -1.4$ m).

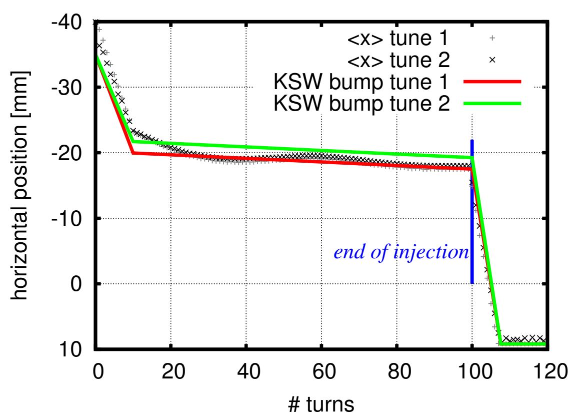

Figure 1: Amplitude of the KSW bump and average beam position during injection.

With regard to the vertical plane, the injection offset is 8 mm for tune 1 and 7.5 mm for tune 2. We are equally able to produce the required emittance by adjusting the offset and the KSW waveforms, as we can see in Fig. 2, as the final emittances (at the end of injection) are $\epsilon_{N,x} = 13\mu$m and $\epsilon_{N,y} = 6\mu$m.

The evolution of the horizontal emittance is equivalent for both tunes and it stabilizes at the end of the injection process. In the vertical plane, the situation is different. For tune 1, the emittance stabilizes after approximately 25 turns, while for tune 2, it grows much faster during the first 5 turns, and then it stays almost constant.

Beam Losses at Injection

Figure 3 represents the instantaneous losses during injection. The total accounts for 2.5%. Aiming at larger emittance would cause unacceptable beam losses at injection, the vertical plane being the most critical one. We can observe that there is a peak in the instantaneous losses when the vertical emittance attains its maximum value. After that, the losses

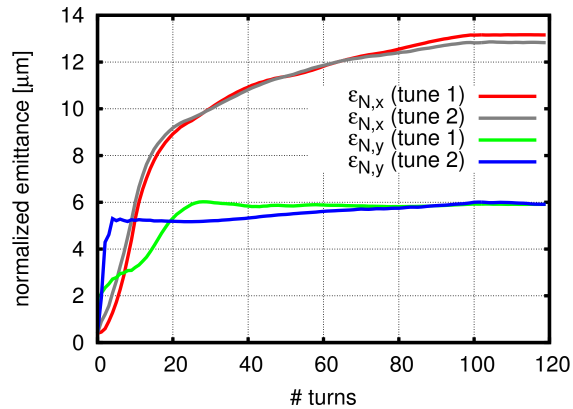

Figure 2: Normalized emittance evolution during injection.

increase due to the fact that the horizontal emittance is still growing up, and then they go down.

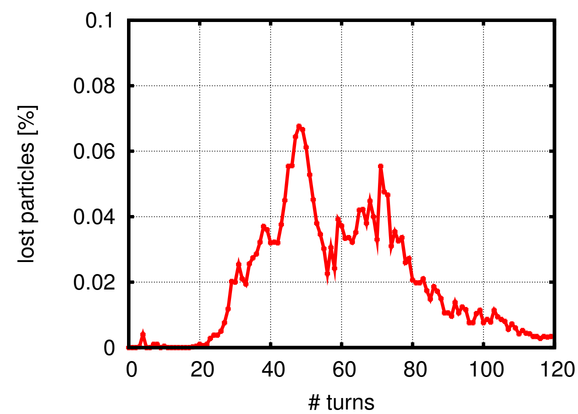

Figure 3: Percentage of particles lost in each turn (wrt the total injected particles) during injection for tune 1.

We can see transverse position of the particles at the moment they were lost in Fig. 4.

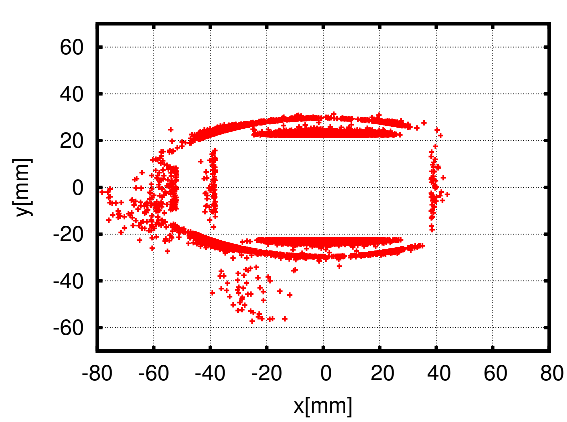

Figure 4: Loss map for for tune 1.

These losses occur mainly in the beam scope window. The present baseline for the beam scope assumes an aperture of

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38.2 mm [H] and 22.4 mm [V] [6]. A larger dimension of the beam scope would reduce the losses at this element but the losses would be then distributed around the machine. The function of this element is to absorb the particles that would be otherwise lost in the PSB ring. The other pattern that we observe corresponds to the scrapers that are located around the machine, and whose shape is an ellipse with dimensions 61 mm [H] and 29.5 mm [V].

Tune

The target emittance could be achieved at the end of injection for the two studied tunes. As for the LHC beams, we had to adjust the KSW waveforms and the vertical offset to the specific tune due to its influence on the injection process. This influence can be seen in the transverse phase space. The phase space distribution after 10 turns is shown in Fig. 5 for the horizontal plane and in Fig. 6 for the vertical one. We can observe that with tune 2 the vertical injection offset allows filling the transverse phase space in 10 turns while for tune 1, since it is very close to 0.5, one has to wait for filamentation to take place and the target emittance is reached in ~ 30 turns. This explains the difference in vertical emittance evolution observed in Fig. 2.

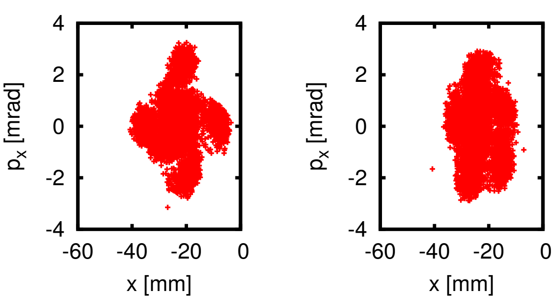

Figure 5: Horizontal phase space distribution after 10 turns for tune 1 (left) and tune 2 (right).

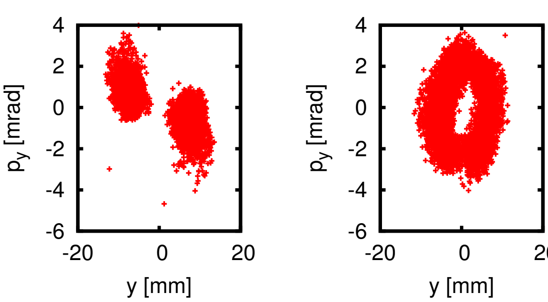

Figure 6: Vertical phase space distribution after 10 turns for tune 1 (left) and tune 2 (right).

Transverse Beam Profile

Figure 7 shows the horizontal beam profile evolution for the base line working point (tune 1). The first ramp in Fig. 1, that corresponds to the first 10 turns, allows to quickly fill the core of the distribution, avoiding an excessive density in the core and relaxing the effects from space charge. The second ramp is slower and permits to fill the outer part of the distribution.

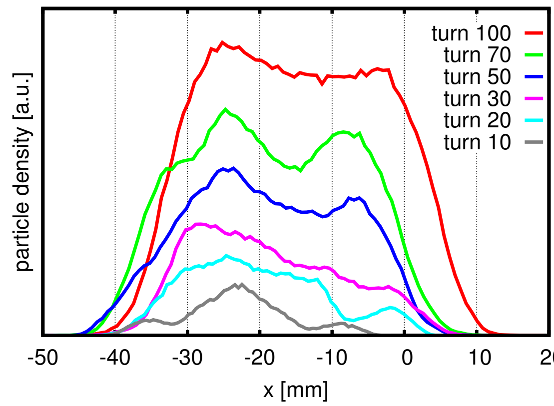

Figure 7: Horizontal beam profile evolution during injection (tune 1).

The vertical beam profile evolution is shown in Fig. 8. Due to the initial offset at injection, we observe a double-head profile that at the end of injection starts converging to a Gaussian distribution. This behavior is observed also in the ISIS synchrotron, that also makes use of the H^- injection [5].

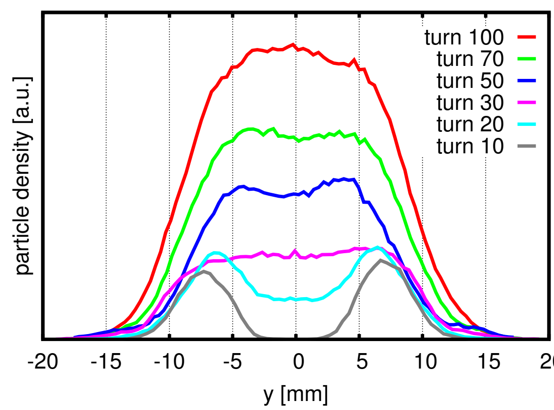

Figure 8: Vertical beam profile evolution during injection (tune 1).

CONCLUSIONS

We have performed simulations to asses how Linac4 and the H^- injection in the PSB can provide to its different users the required beam characteristics. In particular, we studied the case of LHC and high intensity beams. We have analyzed the difference in the injection process for the two beams and for two different working points of the PSB. In all cases we have been able to produce the desired emittance at the end of the injection process.

For the particular case of the high intensity beams, we have found a limit in emittance of $\epsilon_{N,x} = 13\mu m$ and $\epsilon_{N,y} = 6\mu m$ if we want to keep the injection losses below 2.5%.

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REFERENCES

[1] LIU website: https://espace.cern.ch/liu-project/default.aspx

[2] E. Forest, A. Molodozhentsev, A. Shishlo, J. Holmes. “Synopsis of the PTC and ORBIT Integration”, KEK. Internal Report (A), 4 November, 2007.

[3] E. Benedetto *et al*., “Transverse Emittance Preservation studies for the CERN PS Booster Upgrade", HB’2014, East Lansing, USA. p. 428.

[4] E. Benedetto *et al*., “CERN PS Booster Upgrade and LHC Beams Emittance”, IPAC’15, Richmond, USA.

[5] B Jones *et al*., “Injection Optimization on the ISIS Syncrotron," Proceedings of EPAC08, Genoa, Italy. p 3587.

[6] Matthias Scholz, “Simulations of the H- Charge Exchange Injection into the CERN Proton Synchrotron Booster with Linac4”. Thesis.