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UPGRADES OF THE CERN PS BOOSTER EJECTION LINES

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Abstract

The PS Booster extraction energy will be augmented from 1.4 to 2 GeV to reduce intensity limits due to space charge at the PS proton injection. For this upgrade the transfer line between PS Booster and PS will be modified for 2 GeV operation and pulse to pulse optics modulation for different beam types. Also the PS Booster measurement line will be upgraded to 2 GeV and shall provide improved optics solutions for emittance measurements while reducing the loss levels recorded during operation. This paper describes the foreseen optics solutions for both transfer lines.

INTRODUCTION

The four PS Booster (PSB) rings are recombined with two sets of recombination septa and kickers in the first part of the BT line, Fig. 1. A horizontal switching dipole at the end of the BT line allows to send the beam either to the PS (BTP line) or into a measurement line (BTM) terminated by a dump. From the BTM line a vertical branch off leads to ISOLDE (BTY). The BTM line serves mainly for emittance measurements in both planes and therefore has to accept all beam types and beam energies extracted from the PSB.

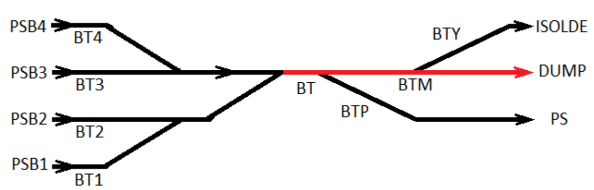

Figure 1: Scheme of the PSB ejection lines, not to scale.

Within the LHC Injectors Upgrade (LIU) the PSB extraction energy will be augmented from 1.4 to 2 GeV to reduce intensity limits due to space charge at PS injection [1]. All the beam transfer hardware between PSB extraction and PS injection (BT-BTP) has to be upgraded for the 30% increase in beam rigidity. The required exchange of the quadrupoles in BTP will be used to rearrange the focussing structure such, that the present mismatch in horizontal dispersion at the PS injection and the consequent emittance blow up can be avoided. The new quadrupoles will be made of a laminated design to facilitate pulse-to-pulse modulated (ppm) operation and thus, give the possibility to adapt the optics to different beams. Also the hardware in BTM needs to be upgraded. During the long shutdown one (LS1) at CERN, the BTM dump was exchanged [2] to withstand the beams with higher brightness after the connection of Linac4 and PSB the energy upgrade to 2 GeV. The BTM upgrade must not hinder a potential energy upgrade of also the BTY line to ISOLDE. The following paragraphs describe the proposed optics solutions for the BTP and the BTM lines.

PSB-PS OPTICS

The future ppm capability of BTP allows to use dedicated optics solutions for different beams. The beams distributed by the accelerators PSB and PS can be categorized into three different beam types as shown in Table 1.

Table 1: Normalized rms Emittances and Momentum Spreads of the Different Beam Types in the PS Complex

Beam	$\epsilon_{N,x}[\mu m]$	$\epsilon_{N,y}[\mu m]$	σ_δ
LHC	2	2	1.07×10^{-3}
Fixed target	10	5	1.35×10^{-3}
ISOLDE	15	9	1.35×10^{-3}

Three different optics requests have to be fulfilled at PS injection. First, remove the horizontal disperson mismatch for LHC and high-intensity fixed target (FT) beams to reduce emittance blow up in the PS which consequently results in improved LHC luminosity and reduced losses for FT beams. Second, squeeze large emittance FT beams at the injection point to reduce the losses and radiation. Third, preserve the existing mismatched optics as a fallback solution in case of space charge induced problems in the PS. In the following plots the half beam sizes are calculated as

$$A_{x,y} = n_\sigma \sqrt{k_\beta \beta_{x,y} \frac{\epsilon_{N;x,y}}{\gamma_r \beta_r}} + \left| k_\beta D_{x,y} \sigma_\delta \right| + c.o. \sqrt{\frac{\beta_{x,y}}{\beta_{max;x,y}}}; \quad (1)$$

where β and D denote the betatron and dispersion functions with their uncertainty factor k_β, ϵ and σ_δ the distributions of emittance and momentum spread, $c.o.$ the trajectory variation and γ_r and β_r the relativistic parameters. The beam sizes are calculated for $n_\sigma = 3$, $k_\beta = 1.2$ and $c.o. = 3$ mm.

LHC Beam Optics

This optics aims primarily at matching all optics functions – except the vertical dispersion – to the PS injection settings. The vertical dispersion varies within a bunch train depending on the production ring in the PSB and thus different vertical deflections in the recombination lines. Its value is kept below 50 cm at PS injection for all 4 rings. The horizontal dispersion can be matched by adding one quadrupole in BTP and rearranging the quadrupole positions, Fig. 2. The beam envelope fits nicely within the physical aperture. The main difficulty for this optics lies in keeping the minimum beam size at least at the level of the present optics to avoid space-charge effects due to Linac4 beams with increased brightness.

High Intensity FT Beam Optics

Beams produced from the PSB have a linear brightness behaviour. Thus the high intensity FT and ISOLDE beams

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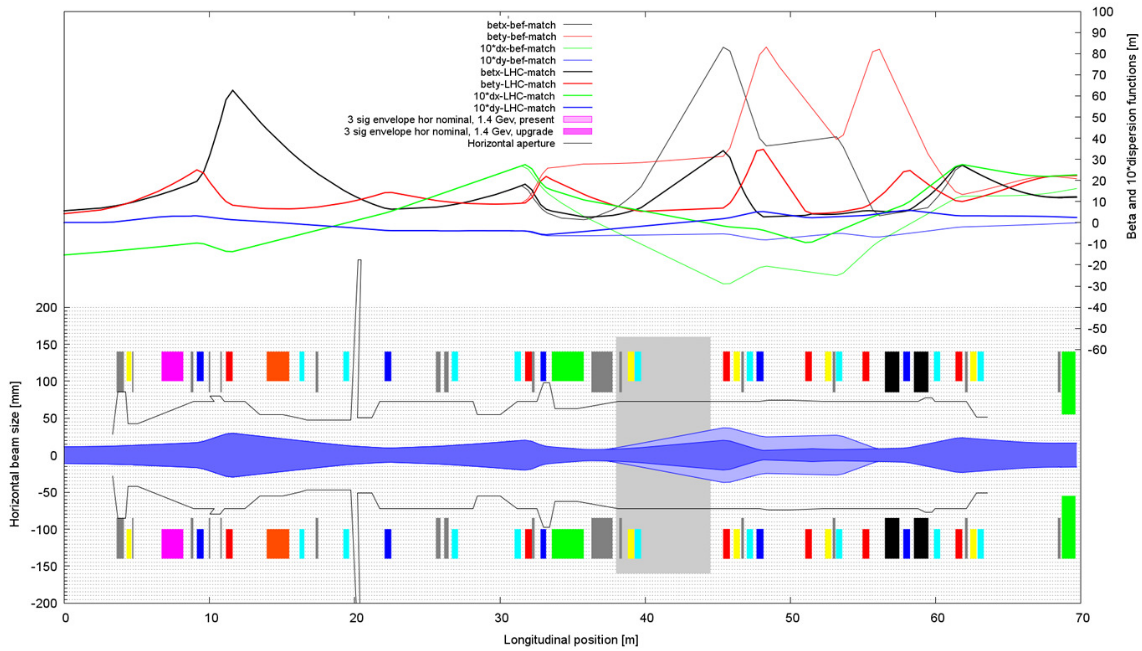

Figure 2: Optics functions from PSB ring 4 extraction to PS injection (BT-BTP) in the top, present optics (thin lines) and proposed optics for the upgrade (thick lines). The bottom part shows the horizontal beam envelope for the present optics in light and for the proposed optics in dark shade. The grey line represents the physical aperture.

in Table 1 have large emittances. The main aim of equipping the BTP line with laminated quadrupoles is to allow for a dedicated FT beam optics to reduce losses during the injection process for the large emittance beams. The proposed optics solution presents a beam size reduction at the aperture bottle neck in the shielding wall between PSB and PS and in the PS injection septum. This optics requires a dedicated injection optics also in the PS to peform a matched transfer.

Due to the new focussing structure, the present optics at PS injection had to be rematched. One horizontal and two vertical aperture bottlenecks could be improved.

Trajectory Correction Studies

The new quadrupole positions in BTP necessitated a rearrangement of corrector and monitor positions. A trajectory correction study was performed to validate the new design. Quadrupole positions are simulated with an rms misalignment of 0.2 mm in the longitudinal and transverse planes. Dipoles, correctors and monitors with an rms misalignment of 0.3 mm. All elements are simulated distributed with an angular misalignment of 0.3 mrad. Relative rms errors of the integrated field are assumed as $1 \cdot 10^{-3}$ for quadrupoles. The particle positions and angles at the line start are distributed according to the phase space distribution.

The maximum trajectory peaks can be reduced by about a factor 10 after correction and fit within the trajectory variation contribution of the beam envelope calculation. In the horizontal plane the extraction septum needs to be deployed as correction knob due to the lack of horizontal orbit correctors in the first part of the recombination. The septum can provide about 2 mrad for steering if the trajectory is optimised in the extraction channel with respect to the available aperture. In the vertical plane there are many correction possibilities due to the vertical recombination dipoles and thus, the trajectories can be well corrected.

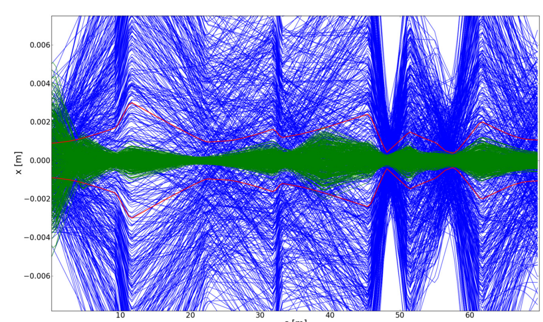

Figure 3: Uncorrected (blue) and corrected (green) trajectories for 500 seeds from PSB extraction to PS injection. The red line represents the trajectory variation contribution in the beam envelope calculation.

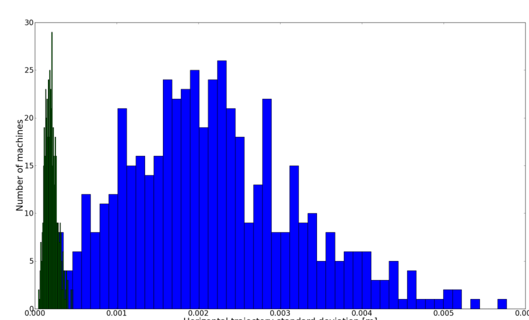

Figure 4: Histogram of the uncorrected (blue) and corrected (green) horizontal trajectory standard deviation.

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MEASUREMENT LINE OPTICS

There are four different optics configurations for the BT-BTM line [3]. One optics setting is dedicated to dump the beam or send it to ISOLDE. Two settings are used for horizontal and one setting for vertical emittance measurements. For LHC beams with large momentum spread the horizontal small-D_x optics is used to minimize the emittance measurement error due to the dispersion contribution to the beam size. However, this optics presents aperture bottlenecks for large emittance beams and thus, the large-D_x optics is used for FT and ISOLDE beams where the dispersive part of the beam size is negligible. Figure 5 represents the scheme of the line. BT.BHZ10 is the horizontal switching dipole between BTP and BTM line and BTY.BVT101 is the vertical switching dipole to ISOLDE.

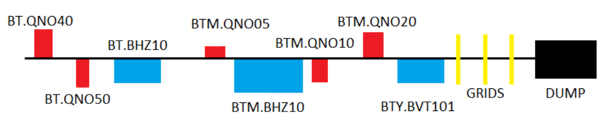

Figure 5: Scheme of the BT-BTM line. Quadrupoles are shown in red and dipoles in blue. It corresponds to the red line in Fig. 1.

Limitation of Present Optics

During the specification for the new design of the dipole BTM.BHZ10 the aperture requirements exceeded the actual physical aperture even though presently 1.0 GeV beams are used in BTY which will be deprecated after the 2 GeV energy upgrade. Increased levels of radiation from the annual radiation survey in 2013 downstream of this magnet confirm two aperture bottlenecks at BTM.BHZ10 (A_y) and BTM.QNO20 (A_x). A new optics solution reducing the beam size at these locations and therefore the required vertical gap in the strong dipole BTM.BHZ10 is proposed.

Proposed Optics for BTM

A new full set of optics has been designed, by rematching the quadrupoles BT.QNO40, BT.QNO50, BTM.QNO05, BTM.QNO10 and BTM.QNO20. Due to the emittance measurement with three grids the following optics constraints have to be met. $\alpha = 0$ at the central grid, 60^o phase advance between adjacent grids and minimization of the normalised dispersion vector $\frac{D^2}{\beta} + \left(\alpha \frac{D}{\sqrt{\beta}} + \sqrt{\beta} D'\right)^2$. In Figs. 6 and 7 the beam envelopes for the present and proposed optics are compared. These beam envelopes are calculated for all the optics configurations and for the largest beam (ISOLDE).The beam size corresponds to Eq. 1, with n_σ=3, k_β=1.2, $c.o.$=1.5 mm for the lowest energy (E_k=1.4 GeV) after the PSB energy upgrade. The beam size could be reduced by 35% at the vertical and by 20% at the horizontal aperture bottlenecks, respectively. Also, the new optics allows to slightly improve the measurement conditions with respect to the present optics. The specified beam sizes at the new PSB dump were not exceeded [2] and the optics functions at the vertical branch off to ISOLDE only marginally changed. The required quadrupole strength are within present limits to test the new optics during the 2014 run; for the energy upgrade most of these magnets will be exchanged.

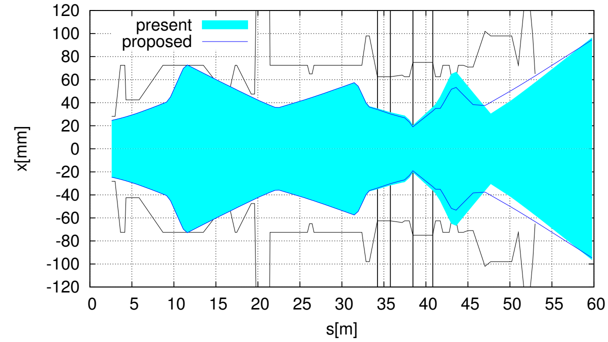

Figure 6: Aperture envelope in the horizontal plane.

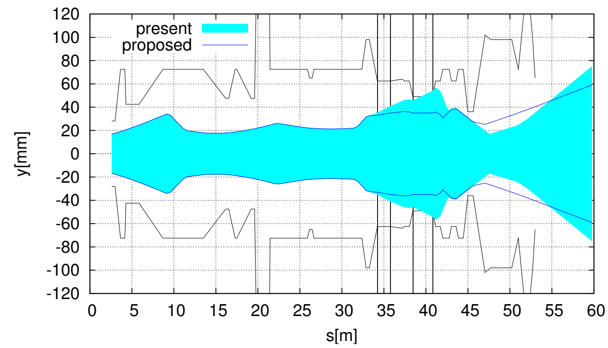

Figure 7: Aperture envelope in the vertical plane.

CONCLUSIONS

The proposed optics solutions for the PSB ejection lines allow for reduced emittance blow up and removed aperture bottlenecks at PS injection for LHC and FT beams, accomplished with a new focussing structure in the BTP line. The functionality of the correction scheme with the proposed rearrangement of instrumentation and correction elements was validated. The new optics in the measurement line provides a reduced beam envelope at critical aperture locations and thus a potential reduction of beam losses and the associated radiation levels. The reduced vertical beam size in the strong horizontal bending magnet BTM.BHZ10 will significantly ease the magnet design. The emittance measurement conditions are slightly improved. These optics settings will be tested in the machine during 2014.

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