UPGRADES FOR THE CERN PSB-TO-PS TRANSFER AT 2 GEV

W. Bartmann, B. Balhan, J. Borburgh, J. Cole, S. Gilardoni, B. Goddard, O. Hans, M. Hourican, L. Sermeus, R. Steerenberg, CERN, Geneva, Switzerland, C. Yu, IHEP, Beijing

Abstract

The CERN PS Booster extraction energy will be upgraded from 1.4 to 2.0 GeV to alleviate the direct space charge tune shift in the PS. The focussing structure of the transfer line will be modified in order to better match the optics between the PSB and the PS. The optics of the PS at injection and, with it, of the transfer line can be adapted to reduce the continuous losses from the already injected and circulating beam bumped towards the septum. Experimental results of the optics optimisation and probing the injection kicker flat top are shown. Modifications of the recombination septa and the main horizontal bending magnet in the measurement line are presented.

INTRODUCTION

Within the upgrade of the PSB extraction energy the transfer line quadrupoles in the PS access zone will be exchanged to allow for pulse-to-pulse modulated optics settings. The present mismatch at PS injection shall be overcome by a new design of the focussing structure. The following paragraphs present measurements of the injection kicker flat top ripple, injection losses for a dedicated PS injection optics and foreseen hardware changes of the recombination septa and the main horizontal bend in the measurement line (BTM.BHZ10).

PS INJECTION KICKER RIPPLE

Besides the classical LHC-beam production scheme based on injection on the 7th harmonic and triple splittings, an alternative one is based on batch compression and batch merging of 8 bunches injected on the 9th harmonic [1].

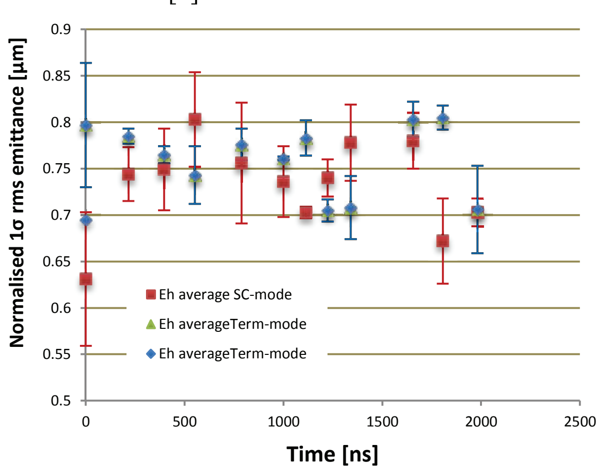

Figure 1: Horizontal emittance measurements for the injection kicker in terminated and short-circuit mode.

Since the relative emittance increase for this small emittance beam due to the injection kicker ripple could be important, measurements of the emittance in the PS on the full kicker pulse length for short-circuit and terminated mode have been performed on June 28th, 2012. Figure 1 shows the resulting emittance measured for the injected beam for different kicker timing delays. Taking into account the error bars, there is little difference in emittance for short-circuit and terminated mode. In general, the flat-top ripple is small, the bunch at t=0 is close to the edge of the kicker pulse and slight fluctuations in the kicker timing or bunch phase change the emittance significantly. This measurement point was repeated several times and observations of the direct analog signal of the kicker discharge with respect to the bunch show that different parts of the bunch were indeed kicked differently.

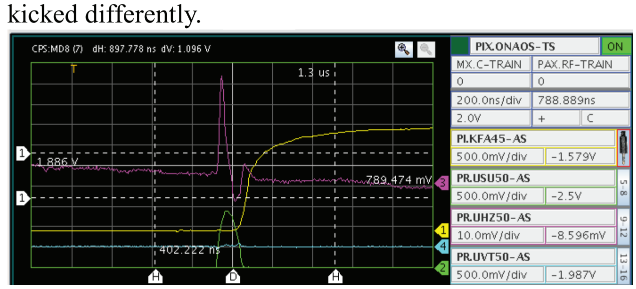

Figure 2: For the kicker timing t=0 only part of the bunch (red curve) is kicked due to slight fluctuations of the kicker delay and bunch phase.

PS INJECTION LOSS MEASUREMENTS

The proton injection region in straight section 42 in the PS tunnel marks a critical position with respect to ambient dose rates on the road passing above outside the tunnel. Losses at injection appear due to single passage losses in the injection channel of septum SMH42 and due to continuous losses from the bumped circulating beam being scraped off by aperture bottlenecks in the injection region for about 500 turns [2].

In order to reduce these losses, a dedicated optics which optimises the beam sizes in the PS injection region was calculated deploying the special quadrupoles used to change the optics at extraction (QKE16). Using these quadrupoles, the optics of about the full PS ring is distorted. Depending on the results of these tests, new dedicated quadrupoles could be installed to allow for the optics changes to be only locally in the injection region. The optics in the PSB-to-PS transfer line was rematched using a quadrupole which is not used in normal operation due to its inaccessible and thus unmaintainable location in the separation wall between PSB and PS.

ISBN 978-3-95450-122-9

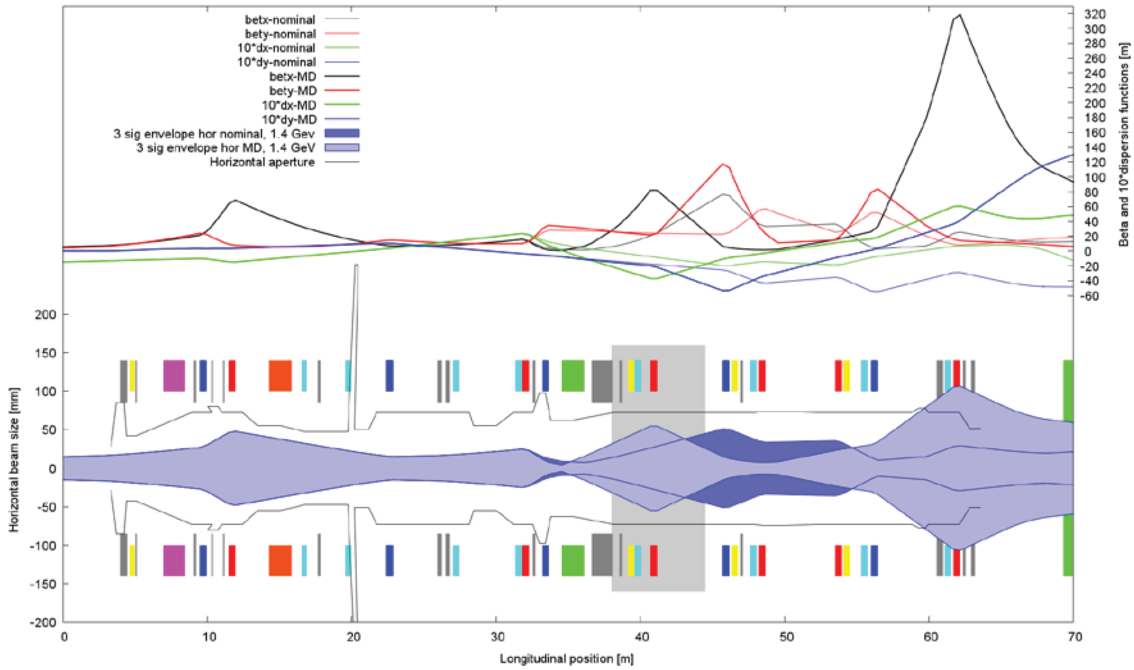

Figure 3: 3σ beam sizes of the nominal and measurement beam (lower part) and the optics for both cases (top part).

On February 12th, 2013, the effect of the new optics on the injection losses was measured and resulted into an unexpectedly low beam transmission at PS injection.

Extensive re-steering of the trajectory and inverting the polarity of the rarely used quadrupole did not improve the transmission losses to be better than 30% compared to a nominal value of about 10%.

The beam intensity during the measurement was between 2.8 and $2.9 \cdot 10^{12}$ particles with a momentum spread in the PSB of $1.07 \cdot 10^{-3}$. The emittances measured in the PS are shown in Table 1. While the emittance in the vertical plane remains conserved, there is an emittance growth of 75% in the horizontal plane.

Table 1: Emittances during injection loss MD

(1σ rms, normalised) [μm]	**Nominal optics**	**Dedicated optics**
Horizontal emittance	3.6	6.4
Vertical emittance	2.9	2.7

All element positions in the PSB and its transfer lines were revisited. As a result the quadrupoles between the wall separating the PSB from the PS and the PS injection were found to be misplaced by about 1 m in the MADX model [3].

In order to re-simulate the measurement conditions, the quadrupole positions in MADX were adjusted while leaving their currents at the values rematched for the PS injection optics. Figure 3 shows the resulting optics in the PSB-to-PS transfer line. There are no significant differences until the first quadrupoles after the wall (grey shaded area); the last defocussing quadrupole (blue bar) causes the horizontal beta function to go up to 320 m in the last focussing quadrupole (red bar) where the beam is too big for the available aperture. The 3 σ beam sizes are plotted for the nominal case (dark blue) and the measurement case (light blue), including linearly the dispersion, 20% beta beating and ±1 mm trajectory variation. For this optics, 1.4 σ of the beam fit into the aperture, including dispersion and trajectory variations. Comparing the 70% transmission measured in the PS with a theoretical Gaussian distributed beam, this value corresponds to 1.55 σ betatron beam size. As seen in the optics functions in Fig. 3, there is only very little optics detuning in the vertical plane. The emittances shown in Table 1 are measured with grids in straight section 48, 52 and 54 (compare to injection in 42). The measured growth in the horizontal plane is supposed to stem from to wrong betatron functions at the measurement location rather than filamentation which is too slow to affect the beam size on this time scale. The difference in horizontal and vertical plane for the emittance growth is reflected by the different optics detuning in the line.

RECOMBINATION SEPTA

The recombination septa in the transfer line, BT.SMV10 and BT.SMV20, are identical magnets, but in purpose built vacuum vessels, taking into account the available space. Each vacuum vessel also provides space for a beam observation system. The present BT.SMV10 septa (used to recombine the ring 4 to ring 3 and ring 1 to ring 2) are operated slightly below their design current of 27.3 kA. The BT.SMV20, used to recombine ring 2 into ring 3, is designed for use at an angle of 73.2 mrad; therefore the BT.SMV10 septum is most critical. To upgrade the septa for extraction up to 2 GeV, it is vital to maintain their expected lifetime at present values. The

ISBN 978-3-95450-122-9

solution is therefore to increase the magnetic length of the magnets. To minimise the cost, the existing vacuum vessel shall be used, retaining the current remote displacement system and supports. This means that the magnets can be lengthened by 240 mm assuming the beam observation systems are moved to the adjacent vacuum chamber. To provide sufficient beam acceptance for the 2 GeV beams (acceptance H×V 62 × 60 mm), and to deal with the increased beam sagitta in the longer magnets, the magnet gap is increased.

Simulations were carried out [4] for the new magnet design. The principal magnet parameters are shown in Table 2. Due to the increased length of the magnets, the deflection point of the septa will shift downstream by approximately 100 mm, while the vacuum would degrade by 25% compared to the present situation if the pumping speed were kept constant.

It is expected that the lifetime of these magnets (presently around 5 years) will be reduced by 1 year.

Table 2: BT.SMV10 transfer line septum parameters

	1.4 GeV	2 GeV
Deflection angle [mrad]	79.3	80
∫B.dl [mT.m]	566	743
Physical length [mm]	1060	1300
Magnetic Length [mm]	996	1224
Gap height (H) [mm]	60.4	62
Gap width (V) [mm]	102	116
Septum thickness [mm]	5	5
Yoke dimension (H × V) [mm]	200×195	210 × 200
Peak current [kA]	27.4	30.0
Repetition rate [s]	1.2	0.9

BTM.BHZ10 UPGRADE

The BTM.BHZ10 magnet is a water cooled, laminated C-type dipole. Originally stemming from the CERN ISR machine it performs the second part of the horizontal bend towards the PSB measurement and dump transfer line or towards the ISOLDE experiment. For operation at 2.0 GeV the magnet becomes saturated and the existing power convertor will not be able to provide the required current [5]. If simply a new larger convertor is used the cost involved and space required for it becomes unrealistic.

Therefore two alternatives are being considered: adding an additional bending magnet in the line to provide the field that cannot be achieved with the existing magnet, or keeping the existing magnet and power convertor and installing additional coils to the magnet to be powered with an additional power convertor, as shown in Fig. 5. The most cost effective option, which also overcomes the limitations in space for an additional magnet, would be adding additional coils to the existing magnet.

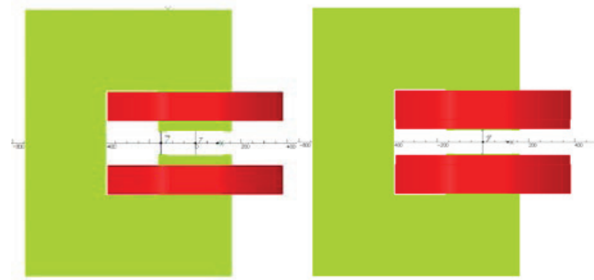

Figure 5: Present coil configuration (left), proposed coil configuration (right).

However, further studies will be required to show that the degraded field quality due to higher saturation levels can be accepted as shown in Fig. 6 or improved with pole shimming.

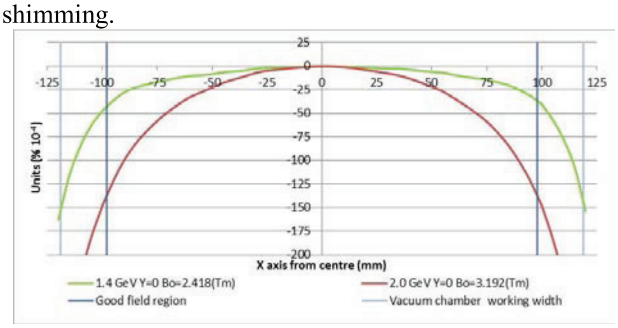

Figure 6: Field homogeneity of the integrated B field along the horizontal axis [$10^4 \cdot (\int By_{(x,0,z)} - By_{(0,0,z)})/By_{(0,0,z)}$].

CONCLUSIONS

Foreseen modifications of the recombination septa and the main horizontal bending magnet in the PSB measurement line for the PSB 2 GeV upgrade were presented.

As a result of measurements of the PS injection kicker flat top ripple with the potential future LHC production beam, only small differences in emittance are expected for the two kicker operation modes at 2 GeV.

Injection loss measurements with a dedicated PS injection optics were affected by a strong mismatch between the transfer line and ring optics due to a divergence in quadrupole positions between model and machine. The analysis with corrected positions shows an agreement between measured and estimated transmission and allows explaining the difference in emittance growth between the two planes. After the long shutdown the new model will be validated and the injection loss measurements repeated.

REFERENCES

[1] H. Damerau et al., “RF Manipulations for Higher Brightness LHC-type Beams”, WEPEA044, these proceedings.
[2] S. Aumon, “High Intensity Beam Issues in the CERN Proton Synchrotron”, PhD thesis, EPFL Lausanne, 2012.
[3] V. Raginel, B. Mikulec, private communication.
[4] V. Pricop et al., “BT10 + BT20 design”, CERN TE/ABT/SE internal report, 2012
[5] J. Cole, S. Pittet “Upgrade study of magnet BTM.BHZ10”, https://edms.cern.ch/document/1282267/1