Particle Accelerators, 1997, Vol. 58, pp. 201–207
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MISMATCH BETWEEN THE PSB AND CPS DUE TO THE PRESENT VERTICAL RECOMBINATION SCHEME

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(Received in final form 10 January 1997)

The production of the nominal LHC beam will demand optimum emittance preservation between individual machines in the injection chain. The edge effects at the entry and exit of the bending magnets used for the vertical recombination of the four PS booster rings to the level of the CPS results in a small un-compensated, and for each ring, different mismatch. We are here presenting recent measurements of the mismatch done in the PSB measurement line.

Keywords: Emittance preservation; Fringe fields

1 INTRODUCTION

The PS booster consists of four parallel, and on top of each other stacked, synchrotrons. The four rings share major elements but can considering correction, compensation, injection and ejection be individually controlled. The filling of the CPS is for most users done with sequential ejection of the four rings. Following ejection the particles from the four rings are brought together in a vertical recombination scheme (Figure 1) to the level of ring 3. The bending magnets used for the recombination are rectangular magnets resulting in some edge-effect contributions to the transverse optics. As this effect during the PSB design stage was foreseen to be of no importance no

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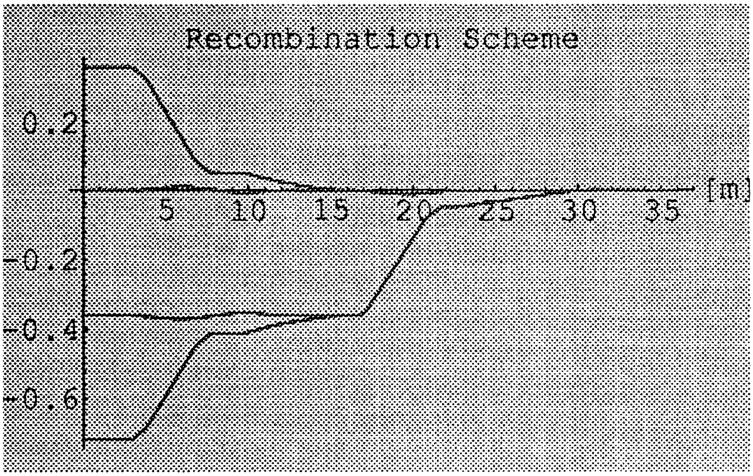

FIGURE 1 General layout of the present vertical recombination scheme in the PS booster. The lines are numbered starting from the bottom.

elements for compensation of the differences between the individual rings were installed. An experimental study, in the PSB measurement line, was performed by Delahaye *et al.*[1] already in 1978 and the effect was then considered sufficiently small to be ignored. However, the tight emittance budget enforced on the injector chain for the Large Hadron Collider (LHC) beam and the resulting demand on good emittance preservation between the individual machines has triggered us to take a new look at the problem. We will in this note present new calculations of the nominal optics based on latest element configuration. The calculations are compared to measurements done in the PSB measurement line and in the CPS.

2 PRESENT VERTICAL RECOMBINATION SCHEME

The recombination scheme[2] can be divided into three main parts. In the first part, the beam-lines from the lower two and the upper two rings are joined together. The recombination is done in a symmetrical manner and therefore one would expect the beams from ring one and four to have the same properties after recombination, and similarly for ring two and three. This symmetry, however, is broken

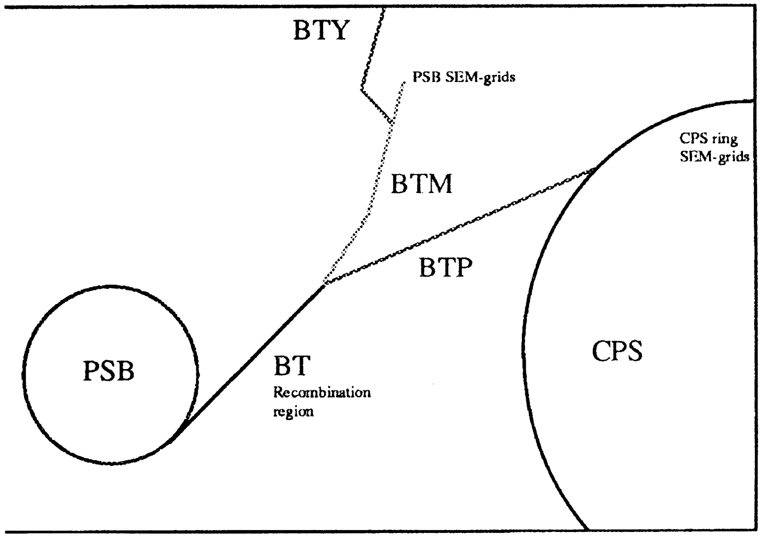

FIGURE 2 General layout of the tranferlines between Booster and CPS

in the next part of the recombination scheme, where the common beam-line from ring two and one is brought to the level of ring three and recombined. Because of this, the beam-lines from the four rings all have different optics. In the two first parts, the beam-lines are equipped with individual steering dipoles, while all the quadrupoles are common. Since the beams in general do not pass through the centre of the quadrupoles, they have a deflecting as well as a focusing effect. In the last part of the recombination scheme, the beams from the four rings are ideally following the same trajectory and this part can be considered as a general transfer line. From here the beam is sent to different destinations, either the CPS, ISOLDE, or the Booster measurement line. Depending on the destination, the settings of the quadrupoles in the last part varies, while the settings of the quadrupoles in the first parts are constant.

An important fact is that the present optics for the transfer line to the Booster measurement line is semi-empirical. To obtain maximum accuracy when measuring the beam with the three secondary emission grids (SEM-grids) in the line, one wants the beam to have a waist at the middle SEM-grid. Hence, the quadrupole settings were calculated in order to achieve this for the beam from ring three. However, it was found when the new optics was tested, that the waist was slightly off-center. It was also found that this could be compensated for by changing the strength of the quadrupole BT.QNO40, the first quadrupole after the recombination. The change had to be made in different directions in order to compensate the horizontal or the vertical plane, and not in the same direction as would have been the case if the measured value of the integrated gradient versus current gdl/I was wrong for this quadrupole. This difference between theoretical prediction and measurements has not yet been properly explained.

2.1 Theoretical Optics

In a first attempt to understand the theoretical optics of the PSB recombination and transfer region we have modelled the recombination scheme using *BeamOptics*,[3] a beam optics package for Mathematica developed by B. Autin *et al.* at CERN. In the calculations, we have used a hard edge model of the magnets, taking into account the edge effects of all the dipoles and the off-axis quadrupoles. Also, we have corrected for the fact that the trajectory inside a bending magnet is slightly longer than the magnetic length of the magnet due to the fact that the beam follows a curved path.

The model has been verified for all beams using an alternative beam optics code. Removing the edge effect from the big bendings in the recombination region results in a very similar optics for the four beams as one would expect. The results using *BeamOptics* for the Twiss parameters at the first SEM-grid in the measurement line are shown in Table I.

The large differences observed in the horizontal plane are almost entirely a result of the horizontal quadrupolar effect at the entry and exit from the rectangular vertical bending magnets.

TABLE I Preliminary theoretical Twiss values deduced with the analytical beam optics program *BeamOptics*. The Twiss values are calculated at the first SEM-grid in the Booster measurement line for the actual settings of the quadrupoles

Plane	*Horizontal*				*Vertical*			
Ring	1	2	3	4	1	2	3	4
β_{Twiss}	6.19	6.62	8.44	7.69	5.94	6.00	6.00	5.94
α_{Twiss}	1.77	2.03	2.54	2.22	1.78	1.78	1.79	1.79

2.2 Mismatch and Beam Blow-up

In a circular accelerator or a storage ring, the Twiss values at all points along the particle trajectory are determined by periodic boundary conditions. Therefore, it is very important that the Twiss values of an injected beam matches the values of the machine at the injection point. Mismatch at injection causes increased betatron oscillations and increase in emittance (emittance blowup). To minimise the emittance blowup, we need to know how much blowup a certain difference in Twiss values will cause. This, of course, will depend on our definition of emittance. If we define the emittance as the area in phase space that contains all particles, the blowup is easy to calculate. Since the phase space ellipse of the injected beam differs from the acceptance ellipse defined by the lattice of the machine, the beam ellipse will start to rotate inside a bigger ellipse, which has the same shape as the acceptance ellipse. After many turns, however, the beam will be smeared out over this new bigger ellipse. A comparison between the area of the injected beam ellipse and this new ellipse gives the blow-up (called mismatch in Table II).

3 MEASUREMENTS

In parallel to the theoretical calculations, measurements have been carried out on the beams in both the Booster measurement line and the CPS. The Twiss parameters have been measured for the beam from all the four rings, and the result has been compared to the theoretical predictions.

3.1 PSB Measurement Line

In the Booster measurement line, the Twiss values of the four beams have been measured using three SEM-grids,[4] and the geometrical mismatch (blowup) with respect to ring three have been calculated. For the measurement, a low intensity proton beam was used. The measurements were repeated at several occasions, well separated in time, to check for long term stability. Possible contributions from (i) beam loss during the transfer and (ii) failed detection of part of the beam at the SEM-grid (in the perpendicular plane to the

TABLE II Measured values at the first SEM-grid in the Booster measurement line

Plane	*Horizontal*				*Vertical*			
Ring	1	2	3	4	1	2	3	4
β_{Twiss}	5.53	4.49	5.52	6.83	5.67	5.51	5.67	5.99
α_{Twiss}	1.63	1.34	1.52	1.94	1.76	1.73	1.74	1.89
Mismatch	11%	26%	0%	24%	2%	5%	0%	7%

measurement plane) were studied without finding any evidence for such contributions. The result is shown in Table II. We see clearly that the beams from the four rings in the horizontal plane are not well matched.

3.2 Comparison between Theory and Measurement

The preliminary theoretical values and the measured values for ring one, two and four in both planes and for ring three in the vertical plane are within reasonable agreement. The much larger deviation for ring three in the horizontal plane could be due to (i) a mistake in the theoretical calculations, (ii) an error in the measurements, (iii) a true difference between the four rings of the local β_{Twiss} value at ejection and (iv) an ejection kicker error in ring three causing an apparent blow-up of the beam. Careful studies of all these possible sources of the observed differences are underway.

3.3 Preliminary Results in CPS Ring

Measurements have also been carried out using three SEM-grids and a beam-stopper in the CPS. However, since the dispersion is large in the CPS, the dispersion effects tends to become significant for the LHC beam with its small transverse beam emittance and introduce systematic errors in the measurement results. Therefore, these measurements have so far been hard to interpret but the preliminary results support qualitatively the PSB measurement line data.

4 CONCLUSIONS

Measurements in the PSB measurement line show that the vertical recombination scheme in the PSB-CPS transfer line introduces a mismatch between the four PSB rings in the horizontal plane. The result is qualitatively supported by measurements in the CPS ring using the existing three SEM-grids. Theoretical calculations agree qualitatively with the measurements and show that mismatch is due to the edge effects at the vertical recombination bending magnets and septa.

The mismatch will be further studied during the coming operational year 1997 using a quadrupolar pick-up and a turn-by-turn single SEM-grid measurement[5] in the CPS. To further study the exact magnitude of the resulting emittance blow-up there is a need for equivalent emittance measurement instruments in both machines. This is foreseen in the PS for LHC project and will probably be realised with the installation of fast wire scanners in the PSB.

Good agreement between the theoretical optics and the measured optics would help in understanding and possibly curing un-necessarily large mismatch between the PSB rings. Furthermore, such an agreement is necessary for the planned implementation of an automated iterative procedure to reduce the mismatch using e.g. the existing ring independent correction quadrupoles in the PSB rings.

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