EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – PS DIVISION

CERN/PS 98-058 (OP)

STUDY OF EMITTANCE BLOW-UP SOURCES BETWEEN THE PS BOOSTER AND THE 26 GeV PS

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The tight transverse emittance budget for the bright beams foreseen for the LHC era demands that all sources of emittance blow-up in the injector chain are reduced to a minimum. A critical region is the transfer between the PS Booster (PSB) and the 26 GeV PS. The four rings of the PSB run with RF harmonic one, and for the LHC beam the PS will be filled with eight bunches originating from two consecutive PSB cycles. Thus, each bunch will be different and has to be individually treated. The present recombination scheme introduces an important difference in lattice parameters between the bunches from different rings. The difference between the bunches would, if left uncorrected, result in a substantial emittance blow-up. Several possible improvements of the recombination stage have been studied, including magnet shims, correction quadrupoles and an RF quadrupole magnet. To complement the theoretical studies, the contribution of mismatch and missteering to the emittance blow-up have been measured using a LHC-type beam, measuring the emittance in the PS with a wire-grid and fast wire-scanners. Results of the calculation and the measurements will be discussed and a strategy to minimise the blow-up will be indicated.

6th European Particle Conference (EPAC'98), June 22-26, 1998, Stockholm, Sweden

Geneva, Switzerland
20 November 1998

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Abstract

The tight transverse emittance budget for the bright beams foreseen for the LHC era demands that all sources of emittance blow-up in the injector chain are reduced to a minimum. A critical region is the transfer between the PS Booster (PSB) and the 26 GeV PS. The four rings of the PSB run with RF harmonic one, and for the LHC beam the PS will be filled with eight bunches originating from two consecutive PSB cycles. Thus, each bunch will be different and has to be individually treated. The present recombination scheme introduces an important difference in lattice parameters between the bunches from different rings. The difference between the bunches would, if left uncorrected, result in a substantial emittance blow-up. Several possible improvements of the recombination stage have been studied, including magnet shims, correction quadrupoles and an RF quadrupole magnet. To complement the theoretical studies, the contribution of mismatch and missteering to the emittance blow-up have been measured using a LHC-type beam, measuring the emittance in the PS with a wire-grid and fast wire-scanners. Results of the calculation and the measurements will be discussed and a strategy to minimise the blow-up will be indicated.

1 INTRODUCTION

The production of the relatively low intensity, but very bright beam for LHC will put high demands on efficient emittance conservation in the injector chain. The injector machines were originally, to a large extent, designed for high intensity beams meaning that some sources for possible emittance blow-up were either ignored or considered irrelevant. A systematic review of all such possible sources has therefore been initiated. The results presented here concern the passage of the beam from the 1 GeV PS Booster (PSB) to the 26 GeV PS.

2 THEORETICAL STUDIES

The sources of emittance blow-up during the beam transfer can be separated in two categories; dynamic sources, which originates from fluctuations in power supplies and magnet imperfections, and static sources that are properties of the nominal optics.

2.1 Dynamic sources of blow-up

The dynamic blow-up sources related to the beam transfer PSB-PS are mainly missteering and betatron mismatch. These are treated within the framework of the Automated Beam Steering (ABS) [1] project and have been found to be manageable.

2.2 Static sources of blow-up

The PSB consist of four vertically stacked accelerators from which beam can be ejected in sequence and recombined at the level of the PS during transfer. The vertical recombination scheme introduces a horizontal mismatch in the Twiss values due to edge effects in the rectangular vertical bending magnets. A theoretical study of this process has already been published [2] and in Table 1 the results expressed as Twiss parameters at a common reference point are given. For the sake of convenience this point was chosen at the first SEM-grid in the PSB measurement line, a line to which the beam can be deviated after the vertical recombination is completed.

Table 1: Theoretical lattice parameter values at the first SEM-grid of the PSB measurement line

Horizontal				
Beam from ring	1	2	3	4
β_{Twiss}	4.96	5.46	6.46	6.14
α_{Twiss}	1.47	1.72	2.06	1.77
Relative mismatch	38%	28%	0%	15%
Vertical				
Beam from ring	1	2	3	4
β_{Twiss}	5.21	5.27	5.27	5.21
α_{Twiss}	1.62	1.62	1.63	1.63
Relative mismatch	1.6%	0.7%	0%	2.1%

3 EXPERIMENTAL STUDIES

The measurements were performed partly in the PSB measurement line and partly in the PS using the available instrumentation. The use of the SEM-grids in the measurement line was motivated by the fact that they can be used without interfering with the production beam. For studies of relative differences between the four PSB rings the further transfer and injection of the beam into the PS is irrelevant.

3.1 Difference between PSB rings

The Twiss values of the recombined beam at the first SEM-grid in the PSB have been measured, in Table 2 the results for the horizontal plane is shown.

Table 2: Measured horizontal lattice parameter values at the first SEM-grid of the PSB measurement line

Horizontal				
Beam from ring	1	2	3	4
β_{Twiss}	4.03	3.90	5.75	5.71
α_{Twiss}	1.19	1.63	1.75	1.59

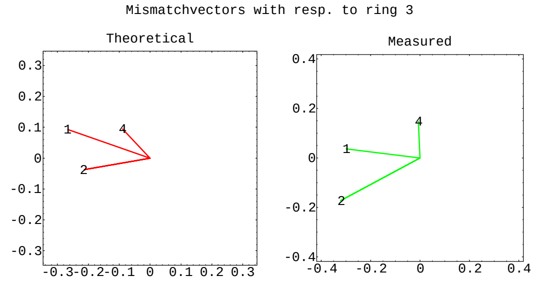

Figure 1: The theoretical and measured mismatch vectors at the first SEM-grid in the PSB measurement line.

The average measured values proved to be within 30% of the theoretical values. However, more interesting is the fact that plotting the experimental and measured mismatch vectors in the same diagram, Figure 1, shows the expected symmetry between the four rings.

Vector addition of the mismatch vector of ring 2 and 4 gives both for the theoretical and experimental values the mismatch vector of ring 1, a symmetry that origins from the symmetry in the used recombination scheme, see figure 2.

3.2 Dispersion mismatch

Measurements have been performed to determine the present dispersion mismatch between the transported beam and the PS lattice. If the momentum spread is σ_p, a dispersion mismatch blows up the rms emittance by [3]

$$\Delta\varepsilon = \frac{\sigma_p^{\ 2}}{2}\left(\gamma \cdot \Delta D^2 + 2\alpha \cdot \Delta D \Delta D' + \beta \cdot \Delta D'^2\right)$$

It is important to note that the absolute blow-up is independent of the beam emittance, while being proportional to the square of the momentum spread. This means that dispersion mismatch is important for small beams with large momentum spread, such as the LHC beam which will have ε=1.1 µm and σ_p=1.25 10^{-3}. The measured numerical value of the expression in

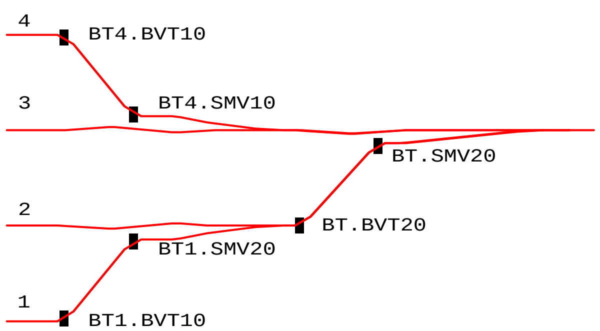

Figure 2: The PSB recombination scheme

parentheses was found to be 0.4-0.5m in the case of the PSB-PS beam transfer. Using the values for the LHC beam, this predicts a rms blow-up due to dispersion of 15-25%, which clearly indicates that dispersion matching is important. Therefore, a change of optics is necessary in order to eliminate the dispersion mismatch.

3.3 Measured emittance blow-up in the PS ring

To validate the theoretical formulae for blow-up due to various kinds of misadaptation, a series of measurements have been performed.

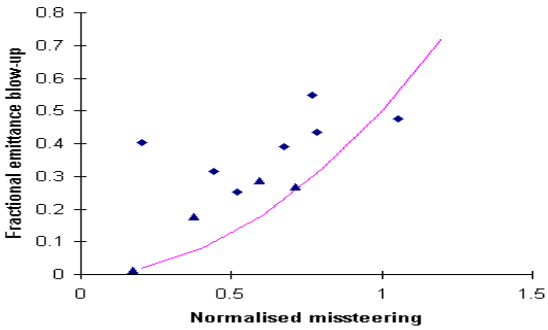

Figure 3: The measured emittance blow-up versus the injection steering error. The line is the theoretical prediction

In the first series, the influence of missteering was studied. The measured values, plotted in Figure 3, shown rather good agreement with the theoretical prediction

In the second series of measurements, the emittance increase due to betatron mismatch was investigated. Here the results (shown in Figure 4) was less obvious to interpret, since a betatron mismatch created by a change in a quadrupole in the transfer line necessarily is accompanied by a dispersion mismatch, if the dispersion is non-zero at the quadrupole as in this case. The measured effect is therefore a combination of the two. However, when this is taken into account, the data followes the theoretical prediction quite well.

4 POSSIBLE IMPROVEMENTS

4.1 PSB recombination scheme

The betatron mismatch from the recombination scheme can only be reduced if additional hardware is added to the recombination line. These additions could include: i) magnets shims for vertical bending magnets, ii) individual quadrupoles in the four PSB lines or iii) a set of RF quadrupoles in the PSB-PS transfer line. The different possibilities have all been theoretically studied. The addition of shims proved effective but unrealistic [4]

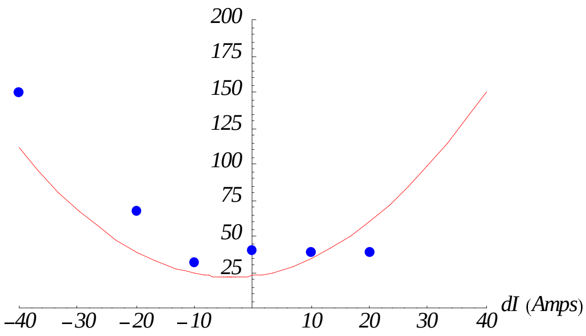

Figure 4: The measured emittance blow-up versus the a quadrupole current. The parabolic curve shows the theoretical prediction.

due to the complicated design of the compact vertical dipoles. The addition of a single quadrupole in ring 2 after the recombination of ring 1 and 2 can reduce the mismatch considerably, see table 2. The focal length of this quadrupole should be 125 m. Constrains on the available space in the recombination line leave this as the only possible additional quadrupole. The possible, but maybe not necessary, use of two RF quadrupoles in the following transfer line could probably render the mismatch entirely negligible.

Table 2: The theoretical mismatch values after recombination using one additional quadrupole in ring 2.

Horizontal				
Beam from ring	1	2	3	4
β_{Twiss}	6.18	6.91	6.86	6.14
α_{Twiss}	1.80	2.10	2.06	1.77
Relative mismatch	13%	2.4%	0%	15%
Vertical				
Beam from ring	1	2	3	4
β_{Twiss}	5.39	5.45	5.27	5.21
α_{Twiss}	1.72	1.72	1.63	1.63
Relative mismatch	6.0%	5.1%	0%	2.1%

4.2 Dispersion at PS injection

The dispersion mismatch can be reduced by modifying the optics of the transfer line. The magnet positions in the line are basically fixed due to lack of space, which means that the possible changes in transfer line optics are constrained to changes in quadrupole gradients. With the 10 presently used quadrupoles, it is not possible to match the lattice parameters and the dispersion to the PS at the same time. However, the line has an eleventh quadrupole which has not been used up to now because of its problematic position inside a shielding wall. With this extra degree of freedom, it is theoretically possible to match the dispersion and the Twiss parameters simultaneously [5]. Test of this matched optics has sofar given better, but not yet perfect, results.

5 CONCLUSSIONS

The theoretical study of possible sources of mismatch between the PSB and the PS points towards several possibly critical points: the used recombination scheme, the dispersion mismatch and the possible drift in steering and betatron parameters at PS injection. The most important of them being the dispersion mismatch. The measurements performed shows that all these effects can be observed as a measurable emittance blow-up of a beam similar to the beam for the LHC. A number of possible improvements have been investigated and it has been shown that the emittance blow-up can be kept within the limits of the foreseen emittance budget for the LHC beam. However, it is doubtful whether that can be achieved without the addition of some hardware in the PSB recombination line.

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