TUNING KNOBS FOR THE PS-SPS TRANSFER LINE

G. Arduini, K. Hanke*, CERN, Geneva, Switzerland

Abstract

Transverse emittance preservation will be an important issue for the LHC injector chain. Minimization of the blow-up at injection by tuning independently the Twiss parameters (α, β), the dispersion D and the dispersion derivative D' is therefore mandatory. The optics of the transfer line between the PS and SPS machines was modeled and matched using the program package *MAD*. Tuning knobs were developed using a singular value decomposition (SVD) algorithm. Coupled to the measurement of the Twiss parameters at a given point downstream of the correction elements they provide a fast correction algorithm for the betatron mismatch.

1 INTRODUCTION

The PS and SPS machines are part of the CERN injector chain for LHC. In the tight transverse emittance budget for the LHC beam a maximum of 17 % blow-up is allocated for the transfer from PS extraction to SPS extraction [1] and only a small fraction of it is assigned to injection mismatch. The injection line must be therefore very accurately matched to the optics parameters of the PS at the extraction point and of the SPS at injection.

The transfer line optics was modeled using the program package *MAD* [2]. The geometry of the model was verified versus the official CERN survey data, while the correct magnetic behaviour was verified in a series of measurements. Based on the model, the line was successfully rematched [3] (and references therein). For the matched optics no blow-up due to mismatch could be detected except for the component due to dispersion in the horizontal plane. The residual mismatch is due both to the unavoidable discrepancy between model and reality and to the uncertainty in the measurement of the initial optical parameters. An on-line measurement of the optics parameters at the injection point together with 'knobs' allowing to tune α, β, D, D' orthogonally is therefore very important.

2 CORRECTION MECHANISM

The developed tuning knobs are based on the inversion of the matrix $\left(\frac{\partial \Delta_i}{\partial K_j}\right)(i, j = 1, ...8)$, where $\Delta_i = (\alpha_{H(V)}, \beta_{H(V)}, D_{H(V)}, D'_{H(V)})$ and K_j is the strength of the j^{th} matching quadrupole [4]. As a first attempt only the eight independent quadrupoles of the matching section controlled from the SPS control room have been considered for simplicity reasons.

Frequently, as in our case, the coefficient matrix for a given optics will be either singular or numerically close to singular. Singular value decomposition (SVD) algorithms provide a tool to diagnose a matrix and to solve the resulting system of equations even for ill-conditioned matrices [5]. An ill-conditioned matrix implies the onset of non-orthogonlity in the variation of the optics parameters as well as a reduced efficiency of the knob for the tuning of some of the optical injection parameters. This could be confirmed with an extensive test of the knob by means of *MAD* simulations: the variations of the quadrupole strengths calculated with the reconditioned inverse matrix for a given optics parameter trim were introduced in the optical model and the resulting modification of the optics parameter at injection was simulated. This showed in particular that the knob was not effective for the trim of β_H.

3 EXPERIMENTAL RESULTS

The tuning tool was tested with beam, using the SPS mismatch monitor [6]. This system is based on a turn-by-turn measurement of the beamsize with an OTR screen and a fast CCD camera. Oscillation of the beam size indicates betatron or dispersion mismatch at injection into the SPS. In the assumption that no dispersion mismatch is present (or at least is known), a measurement of α and β (and of the emittance of the beam) can be performed by measuring the beam profile at three successive turns in the SPS. The Twiss parameters can then be obtained in the same way as from a multi-grid measurement in a transfer line [7].

Since the measurement of the Twiss parameters can be performed much faster than a precise measurement of the dispersion [1], it was decided to detune the horizontal and vertical β-functions and to measure Twiss parameters and mismatch factor using the SPS mismatch monitor. Starting from a matched setting, the β-funcions were detuned by $\pm$10% and $\pm$20%. Figure 1 shows the desired change of the horizontal β-function (dashed line), the result obtained from the simulations above discussed and the measured values. As previously mentioned, already in the simulation the expected variation is not achieved. Only the points for $\Delta\beta$ = 0, -10 m and -20 m could be measured due to a technical problem. For the initial setting ($\Delta\beta$ = 0), the measured value lies already below the theoretical one. This means that the line is not perfectly matched as can be observed also in Figure 2 showing the horizontal geometrical blow-up factor (calculated from the obtained Twiss parameters) as a function of the change of β_H for the same measurement. The above data are consistent with

* Email: klaus.hanke@cern.ch

[1] A faster but, for the moment, less precise measurement of the horizontal dispersion can be performed by measuring at least 5 consecutive profiles [8].

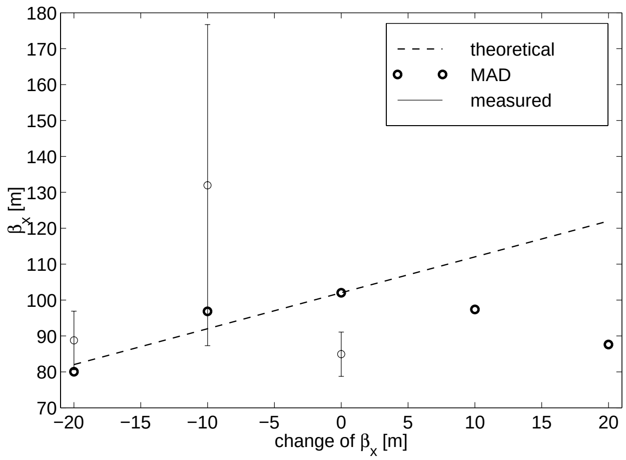

Figure 1: Horizontal β-function at the injection point as a function of the variation applied using the tuning knob. Starting from a matched optics ($\Delta\beta$ = 0), the β-function is detuned by $\pm$ 10 m and $\pm$ 20 m. The expected, simulated and measured behaviour of the β-function is shown.

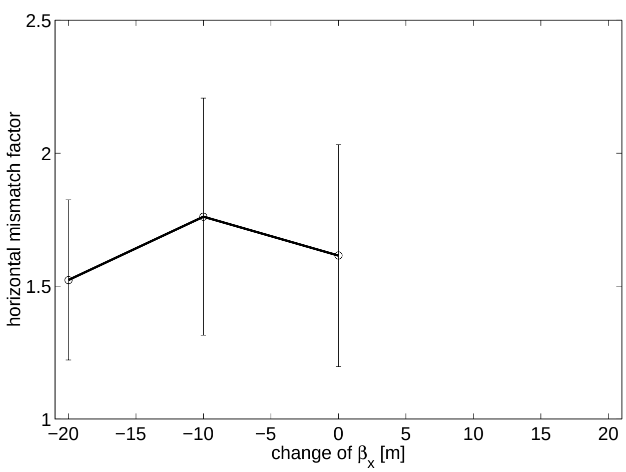

Figure 2: Measured horizontal mismatch factor as a function of the variation applied using the tuning knob.

the horizontal geometrical blow-up of 1.3 obtained from a multi-grid measurement in the line for the matched conditions. Figure 5 shows the horizontal α for the same measurement. Since the knob is orthogonal, it is supposed to stay constant. The significant statistical errors in the measurement can be explained partly by some fluctuations in the beam characteristics provided by the injectors but also by the residual dispersion mismatch present in the matched optics. This constitutes a source of 'background' for the Twiss parameter measurement. The unefficiency of the knob for β_H adjustment, the small number of points available and the large errors make a conclusion impossible for the measurement in the horizontal plane. The same mea-

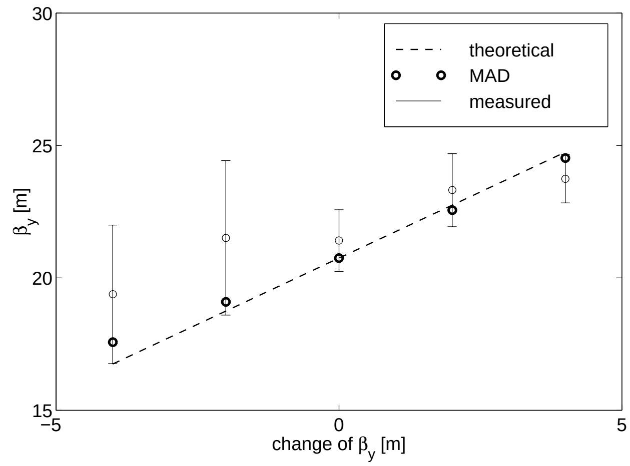

Figure 3: Vertical β-function at the injection point as a function of the variation applied using the tuning knob. Starting from a matched optics ($\Delta\beta$ = 0), the β-function is detuned by $\pm$ 2 m and $\pm$ 4 m. The expected, simulated and measured behaviour of the β-function is shown.

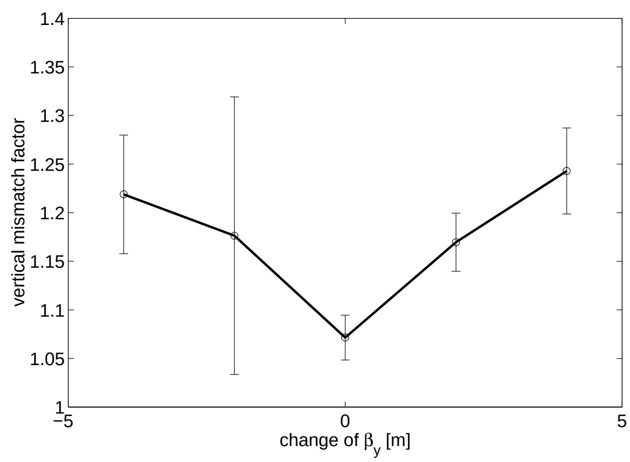

Figure 4: Measured vertical mismatch factor as a function of the variation applied using the tuning knob.

surement was done in the vertical plane. All five settings could be measured, virtually no dispersion mismatch was present for the matched optics and the stabilty of the beam characteristics was excellent. Figure 3 shows theoretical, simulated and measured values of β_V for five different settings of the tuning knob. All data agree within the statistical error. From the same measurement, the vertical geometrical blow-up factor was computed. The result is shown in Fig. 4. For the matched optics ($\Delta\beta$ = 0), a vertical geometrical blow-up factor of 1.1 is found, which is in agreement with the result obtained from a multi-grid measurement in the line [3]. Detuning the β-function at the injection point in both directions leads to an increase of the mismatch fac-

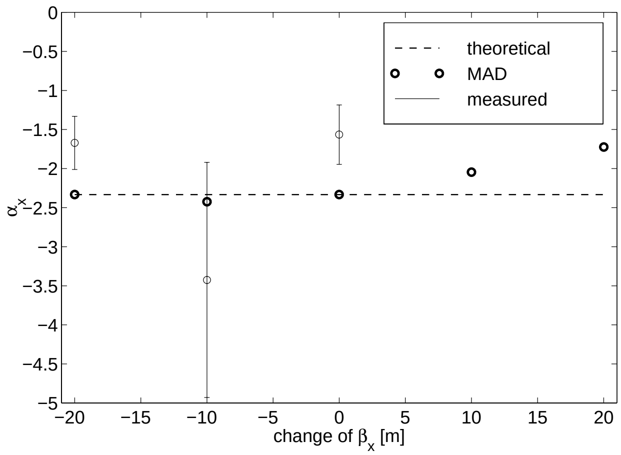

Figure 5: Measured horizontal α for the same measurement as shown in Figs 1 and 2.

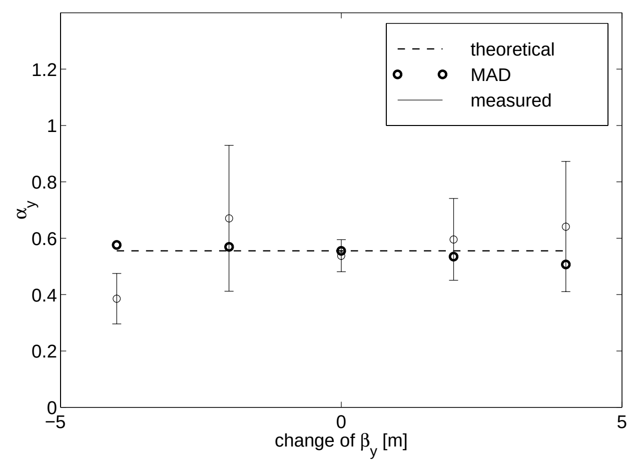

Figure 6: Measured vertical α for the same measurement as shown in Figs 3 and 4.

tor as expected. Figure 6 shows the vertical α for the same measurement. It stays constant within the errors, which means that the tuning knob acts only on the β-function as specified.

For both measurements in the horizontal and vertical plane, also the beam parameters in the other plane were observed. They were found to be unaffected as specified. For details see Ref. [4].

4 CONCLUSIONS AND OUTLOOK

An analytical approach was used to develop a tool for selective orthogonal tuning of the optics parameters in the PS-SPS transfer line. Eight independent quadrupole strengths are used as free parameters to tune eight beam parameters. A coefficient matrix which contains the variation of the Twiss parameters as a function of eight quadrupole strength parameters was generated based on a *MAD* simulation of the line. It was reconditioned and inverted using a singular value decomposition algorithm. The resulting system of equations can be solved and yields the change of quadrupole strength required to obtain a given change of any of the parameters α, β, D, D' at injections while the others remain unchanged. A first measurement with beam, carried out during the 1998 SPS run, allowed to confirm that for the horizontal and vertical β-functions.

It is planned to continue the development and test of the measurement and tuning devices during 1999 and to provide the following enhancements:

- to consider a different set of quadrupoles to get effective variation of all the optics parameters at injection;
- to minimise the source of errors in the measurement by reducing the dispersion mismatch in the horizontal plane for the matched optics;
- to extend the measurement of the effect of the knob not only to all the Twiss parameters but also to the dispersion and its derivative.

5 ACKNOWLEDGEMENTS

The authors would like to thank R. W. Assmann and P. Raimondi for fruitful discussions, R. Jung and his team for the setting-up of the mismatch monitor in the SPS, M. Giovannozzi and D. Manglunki for the setting-up and monitoring of the beam used for the measurement.

6 REFERENCES

[1] P. Collier (ed.), *The SPS as Injector for LHC, Conceptual Design*, CERN-SL-97-07 DI (1997).

[2] H. Grote, F. C. Iselin, *The MAD Program, User's Reference Manual*, CERN-SL-90-13 AP (1990).

[3] G. Arduini, M. Giovannozzi, K. Hanke, D. Maglunki, M. Martini, G. Métral, *Measurement and Optimisation of the PS-SPS Transfer Line Optics*, these proceedings.

[4] G. Arduini, K. Hanke, *Tuning Knobs for the TT2/TT10 Transfer Line*, in preparation.

[5] B. P. Flannery, W. H. Press, S. A. Teukolsky, W. T. Vetterling, *Numerical Recipes in Fortran, The Art of Scientific Computing*, 2^{nd} edition, Cambridge University Press (1986).

[6] C. Bovet, R. Jung, *A New Diagnostic for Betatron Phase Space Matching at Injection into a Circular Accelerator*, LHC project report 3, rev. (1996).

[7] P. J. Bryant, K. Johnsen, *The Principles of Circular Accelerators and Storage Rings*, Cambridge University Press, Cambridge (1993).

[8] G. Arduini, M. Giovannozzi, D. Manglunki, M. Martini, *Measurement of the Optical Parameters of a Transfer Line using Multi-profile Analysis*, CERN PS-Note-98-032 (CA) (1998).