

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. Minimisation of the blow-up at injection by tuning independently Twiss parameters, dispersion and dispersion derivative is therefore mandatory. The optics of the transfer line between the PS and SPS machines was modelled 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 transfer line between the PS and the SPS machines will be an important part of the LHC injector chain [1]. In order to optimise beam and emittance transport, the line must be matched accurately to the measured lattice functions at the PS extraction point and the nominal lattice functions at the SPS injection point.

The transfer line optics was modelled using the program package *MAD* [2]. The geometry of the model was verified versus the official CERN survey data [3], while the correct magnetic behaviour was verified in a series of measurements [4]. Based on the model, the line was successfully re-matched [5]. For the matched optics, we found a betatron mismatch after filamentation of 1.0 in both planes. This clearly fulfils the LHC requirements. The dispersion mismatch after filamentation was computed to 1.7 in the horizontal and 1.0 in the vertical plane¹. The residual mismatch is both due to the unavoidable discrepancy between model and reality and due to the uncertainty in the measurement of the initial optical parameters. It is therefore mandatory to tune selected beam parameters without changing the global setting of the line.

2. Correction Mechanism

To compensate for the unavoidable discrepancies between model and real machine as well as for the errors of the measurement, tuning knobs were developed to tune independently the beam parameters. They are based on the inversion of the matrix $\left(\frac{\partial \Delta_i}{\partial K_j}\right)$, ($i, j = 1, \dots, 8$) 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 quadrupole². As a first attempt only the eight independent quadrupoles of the matching section controllable from the SPS control room have been considered.

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 [7]. Simulations using the reconditioned matrix show that an independent linear variation of all the parameters can be obtained except for β_H for which a non-linear behaviour is observed.

3. Experimental Results

The tuning tool was tested with beam, using the SPS mismatch monitor [8]. This system is based on a turn-by-turn measurement of the beam size with an OTR screen and a fast CCD camera. The oscilla-

¹See Ref. [5] for details.

²See Ref. [6] for details.

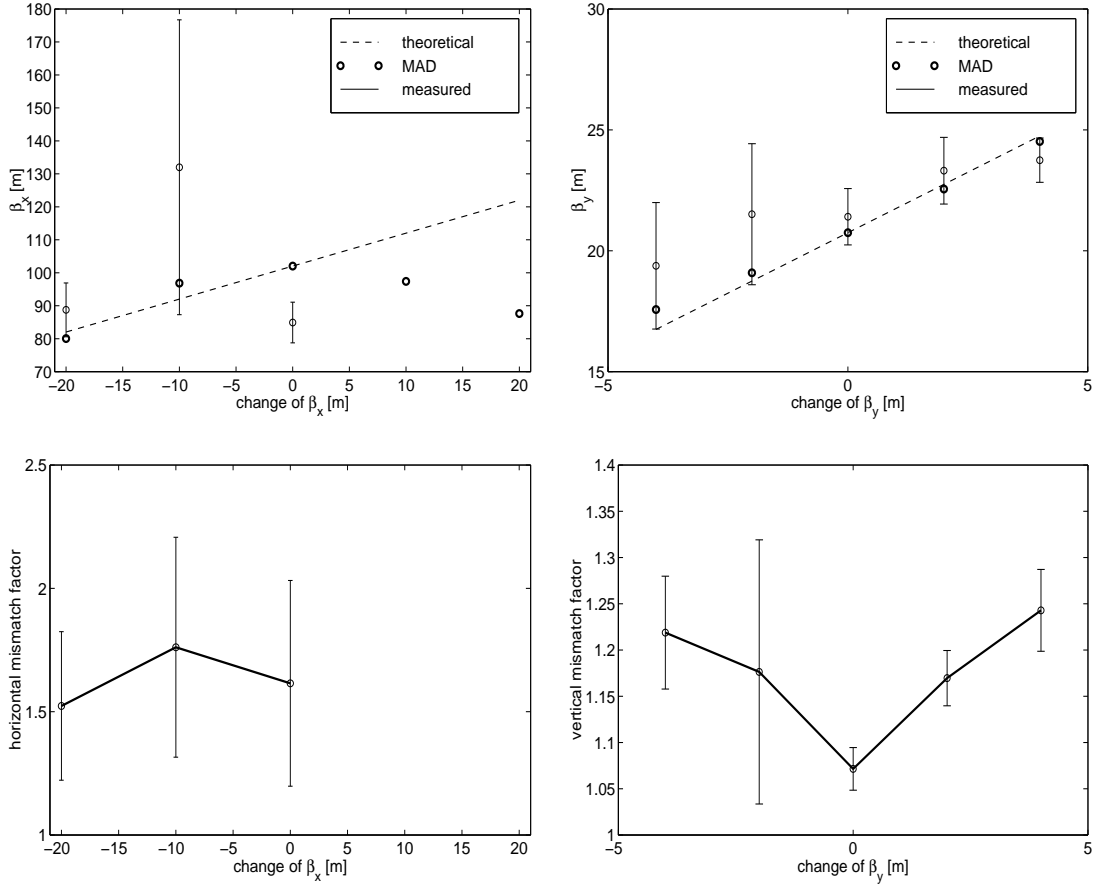


Fig. 1: Horizontal β -function (upper left plot), horizontal mismatch factor (lower left plot), vertical β -function (upper right plot) and vertical mismatch factor (lower right plot) at the exit of the transfer line versus variation applied using the tuning knob. Starting from a matched optics ($\Delta\beta = 0$), the β -function is detuned by $\pm 10\%$ and $\pm 20\%$.

tion of the beam size indicates betatron mismatch at injection into the SPS if no dispersion mismatch is present. While the oscillation of the beam size is a measure of the mismatch, it is important to obtain also the values of α and β . This can be done by measuring the beam profile at three consecutive 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.

Since measurement of the Twiss parameters can be performed quickly, while measurement of the dispersion is time consuming, 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 -functions were detuned by $\pm 10\%$ and $\pm 20\%$. The upper left plot in Fig. 1 shows the expected change of the horizontal β -function (dashed line), the result obtained from the simulation and the measured values. It can be seen, that already in the simulation the expected variation is not achieved. As far as the measurement is concerned, only the points for $\Delta\beta_H = 0, -10$ m and -20 m could be measured due to a technical problem. For the initial setting ($\Delta\beta_H = 0$), the measured value lies already below the theoretical one. This means that this setting is not perfectly matched, which is consistent with a geometrical mismatch factor of 1.3 obtained from a multi-grid measurement in the line [5]. The measurement suffers from significant fluctuations in the horizontal plane which do not allow a conclusion. From the measured Twiss parameters, the mismatch factor can be computed. The lower left plot in Fig. 1 shows the geometrical blow-up versus change of β_H for the same measurement. Again, the measurement suf-

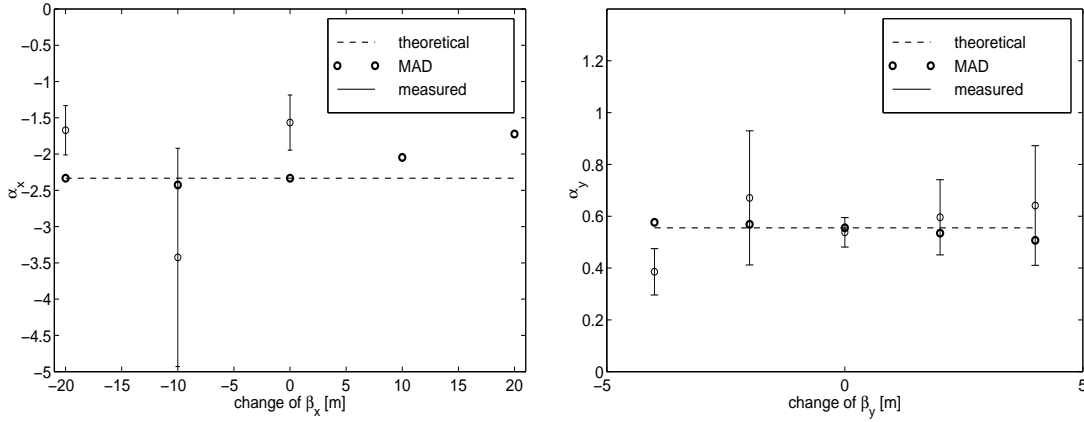


Fig. 2: Horizontal α -parameter (left plot) for the tuning of β_H and vertical α -parameter (right plot) for the tuning of β_V shown in Fig. 1.

fers from significant fluctuations. The α -parameter was computed from the same measurement. The left plot in Fig. 2 shows the variation of α_H , which is supposed to remain unchanged. Also in this case, the statistical error is large and a conclusion impossible. All beam parameters were measured at the same time in the vertical plane, where they are supposed to be unaffected by the variations in the horizontal plane. This is in fact the case. The results are presented in detail in [6].

The same measurement was done in the vertical plane, where all five settings could be measured. The upper right plot in Fig. 1 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 mismatch factor was computed. The result is shown in the lower right plot in Fig. 1. For the matched optics ($\Delta\beta_V = 0$), a geometrical mismatch factor of 1.1 is found which is in perfect agreement with the result obtained from a multi-grid measurement in the line. Detuning the β -function at the injection point in both directions leads to an increase of the mismatch factor as expected. The vertical α -parameter is shown for the same measurement in the right plot in Fig. 2. It remains unaffected by the variation of β_V as specified. All beam parameters in the horizontal plane remained also unchanged during this measurement. The results are presented in detail in [6].

4. Conclusion and Outlook

A straight-forward analytical approach was used to develop a tool for selective tuning of beam 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 Twiss parameters while the others remain unchanged.

A *MAD* simulation showed that the tuning knob works fine for all beam parameters except the horizontal β -function. A first measurement with beam, carried out during the 1998 SPS run, showed that the tuning knob works fine for the vertical β -function. For the horizontal β -function the results do not allow a conclusion.

It is planned to improve the tuning knob by using more magnets as degrees of freedom. It will then be implemented into the SPS control system and provide, coupled to the SPS mismatch monitor, an automated mismatch correction mechanism.

Acknowledgements

The authors would like to thank R. W. Assmann and P. Raimondi for fruitful discussions.

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, J.-Y. Hémerly, M. Martini, *MAD and BeamOptics Description of the TT2/TT10 Transfer Lines - Part I: Optics without Emittance Exchange Insertion*, CERN PS-Note-98-014 CA and CERN SL-Note-98-040 OP (1998).
- [4] G. Arduini, M. Giovannozzi, K. Hanke, J.-Y. Hémerly, *Study of the TT2/TT10 Transfer Line Optics via Transfer Matrix Measurement*, CERN PS-Note-98-020 CA and CERN SL-Note-98-058 MD (1998).
- [5] G. Arduini, G. Crockford, C. Despas, M. Giovannozzi, K. Hanke, D. Manglunki, M. Martini, G. Métral, C. Niquille, *Betatron and Dispersion Matching of the TT2/TT10 Transfer Line for the 26 GeV/c Fast Extraction*, CERN PS-Note-99-007 CA and CERN SL-Note-99-003 MD (1999).
- [6] G. Arduini, J. Colchester, G. Ferioli, M. Giovannozzi, J.-J. Gras, K. Hanke, R. Jung, D. Manglunki, *Mismatch Measurement and Correction Tools for the PS-SPS Transfer of the 26 GeV/c LHC Beam*, in preparation.
- [7] B. P. Flannery, W. H. Press, S. A. Teukolsky, W. T. Vetterling, *Numerical Recipes in Fortran, The Art of Scientific Computing*, 2nd edition, Cambridge University Press (1986).
- [8] C. Bovet, R. Jung, *A New Diagnostic for Betatron Phase Space Matching at Injection into a Circular Accelerator*, LHC project report 3, rev. (1996).