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Measurement of Twiss Parameters and Dispersion in the TT2/TT10 Transfer Line for Indium Ions

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Abstract

For the 2003 Indium ion run, the beam parameters (Twiss parameters and dispersion) have been measured in the TT2 and TT10 transfer lines. These parameters have then been transported back to the beginning of the TT2 using a *MAD* simulation of the beam line. The obtained initial conditions were found to be consistent with those measured in 1998 for lead ions.

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1 Introduction

In order to simulate the optics of the TT2/TT10 transfer line between the CERN PS and SPS machines, the optics code *MAD* has been used. While reference *MAD* input files, which have been thoroughly tested, are available [1], the validity of the simulation depends critically on the input beam parameters. For the 2003 Indium ion run, we have measured the input beam parameters (Twiss parameters and dispersion) in order to have a valid simulation of the beam line. This simulation can then be used for re-matching the whole line, matching of insertions, e.g. at the location of the stripper foil, and evaluation of the emittance blow-up due to the stripping. For the transport of the beam parameters from the location of the beam monitors to the beginning of the line, we have used a *MAD* simulation with the quadrupole settings used in operation and given in Table 1.

quadrupole	current [A]	gradient [m^{-2}]
QFO105	345.70	0.172882
QDE120	160.40	-0.103123
QFO135	154.20	0.0991164
QDE150	123.10	-0.0790319
QFO165	114.10	0.0732271
QDE180	103.30	-0.0662671
QFO205	113.10	0.0725823
QDE210S	169.10	0.110265
QFO215S	188.60	0.123709
QFO375	124.11	-0.107587314
QIID1001	154.47	-0.133519937288
QIIF1002	115.43	0.099783300057
QIID1003	115.11	-0.099502451736
QIF1004	88.10	0.096968290226
QID1005	82.42	-0.090704557816
QIF1006	86.02	0.094672787942
QID1007	85.31	-0.093886849819
QIF1008	77.22	0.084988244486
QID1009	as QID1007	as QID1007
QIF1010	as QIF1008	as QIF1008
QISK101036	0.0	0.0
string type "D"	77.20	-0.084969698948
string type "F"	79.89	0.087920330618

Table 1: TT2 and TT10 quadrupole settings as used for the measurements and simulations reported in this note. The left column gives the quadrupole currents corresponding to the acquisition value. As *MAD* uses the quadrupole gradient, the right column gives the quadrupole gradients calculated from the currents. Quadrupole QFO375 and all following quadrupoles are downstream of the stripping foil and thus operate on fully stripped In^{49+} ions. These quadrupole currents correspond to the operation with stripper in.

The main Indium beam parameters used for the optical parameter measurements made on the SFTION cycle for the physics (with the stripper in) are shown in Table 2. Comparison is given with the 1998 Lead ion measurements.

	Indium (2003)	Lead (1998)
p [GeV/c/u]	6.42	5.11
p [GeV/c/Z]	20.0	20.0
intensity [charges/cycle]	1.8×10^{10}	$1 - 1.5 \times 10^{10}$
ε_H [μm] (normalised, rms)	0.93	2.7
ε_V [μm] (normalised, rms)	1.06	1.2
Δp/p (rms)	2.0×10^{-4}	0.75×10^{-4}

Table 2: Parameters of the In^{37+} beam used during the 2003 experiment and of the Pb^{53+} used in the 1998 experiment (see Ref. [2]).

2 Twiss Parameters

2.1 Measurements in TT2

The Twiss parameters α_x, β_x, α_y and β_y have been obtained from beam profile measurements at three different locations in the TT2 line using Secondary Emission (SEM) wires (MSF257, MSF267 and MSF277). The Twiss parameters are calculated from the measured beam sizes and the transfer matrices between the monitors. Averaging over a series of measurements yields the Twiss parameters at the location of MSF257.

It should be noted, that the measured beam profiles have to be corrected for the contribution of the dispersion. The application program uses theoretically calculated values for the dispersion at the location of the monitors. As will be shown later, the measured dispersion is in good agreement with the theoretical one. Furthermore, the momentum spread of the Indium ion beam is small.

The Twiss parameters have been transported back from MSF257 to the beginning of the TT2 line (entry of quadrupole QFO105) using a MAD simulation of the beam line. This procedure yields the initial Twiss parameters given in Table 3 along with the measured parameters at the SEM monitor MSF257.

location	α_x	β_x [m]	α_y	β_y [m]
MSF257	1.67	17.42	-1.33	28.38
Entry TT2	-2.64	26.53	0.71	6.34

Table 3: Measured Twiss parameters at the location of MSF257 and calculated Twiss parameters at the entry of TT2 derived from the measurements.

2.2 Measurements in TT10

We have repeated the measurement of the Twiss parameters in the TT10 line using the SEM monitors BSG102737, BSG102837 and BSG102937. Averaging over a series of measurements yields the Twiss parameters at the location of BSG102737. Also in the case of the measurements in TT10, the emittance measurement program is based on theoretical values of the dispersion at the monitor locations. Transporting the measured parameters back to the beginning of TT2 using *MAD* yields the initial Twiss parameters. These parameters agree reasonably well with the ones obtained from the TT2 measurements (Table 3) as well as with those measured in 1998 with Lead ions [2]. However, it should be emphasised that the measurements in TT10 were performed with a fully stripped In^{49+} beam and that no correction for the Twiss parameters altered by the scattering process in the stripping foil has been considered. Rough estimate of the Twiss parameter change due to the foil traversal is of the order of 10% [3, 4]. The results are given in Table 4, without the correction for the scattering and energy deposition in the stripper foil.

location	α_x	β_x [m]	α_y	β_y [m]
BSG102737	-1.32	43.45	1.42	55.92
Entry TT2	-2.09	24.44	0.73	6.73

Table 4: Measured Twiss parameters at the location of BSG102737 and calculated Twiss parameters at the entry of TT2 derived from the measurements.

3 Dispersion

3.1 Measurements in TT2

To derive a complete set of optical parameters at the entry of TT2 line, we have also measured the dispersion using the MSF257, MSF267 and MSF277 monitors. To do this, we have changed the momentum of the extracted beam from the PS ring and observed the beam displacement at the location of the monitors. The momentum change can be obtained from a frequency change using the relation

$$\Delta p/p = \frac{\Delta f/f}{\eta} \tag{1}$$

with

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2} \tag{2}$$

where γ = 6.98 [3] and γ_{tr} = 6.12. For each setting, several measurements were taken and averaged. The displacement of the beam in both horizontal and vertical plane was plotted versus momentum change $\Delta p/p$. A linear fit was performed, the slope of which yields the dispersion. Figure 1 shows the measurements in the horizontal plane and Figure 2 in the vertical plane. The dispersion at the location of the three SEM monitors is summarized in Table 5. It is worth noticing, that the sign of the dispersion is a matter of convention. As in the case of the TT2 SEM monitors (vertical plane) a different convention is applied than used in *MAD*, we have in the further analysis flipped the sign of the vertical dispersion.

location	D_x [m]	D_y [m]
MSF257	2.30	-1.14
MSF267	-2.04	-0.63
MSF277	-4.39	0.02

Table 5: Measured horizontal and vertical dispersion at location of SEM monitors.

From the measured dispersion, also the dispersion derivative $D'_{x,y}$ can be obtained. Starting from the transport mechanism

$$\begin{bmatrix} D_{x,y} \\ D'_{x,y} \end{bmatrix}_{point\ 1} = \begin{bmatrix} C_{x,y} & S_{x,y} \\ C'_{x,y} & S'_{x,y} \end{bmatrix} \begin{bmatrix} D_{x,y} \\ D'_{x,y} \end{bmatrix}_{point\ 0} \tag{3}$$

one obtains the two relations

$$D'_{x,y(MSF257)} = \frac{D_{x,y(MSF267)} - C_{x,y(MSF257\rightarrow MSF267)} D_{x,y(MSF257)}}{S_{x,y(MSF257\rightarrow MSF267)}} \tag{4}$$

$$D'_{x,y(MSF257)} = \frac{D_{x,y(MSF277)} - C_{x,y(MSF257\rightarrow MSF277)} D_{x,y(MSF257)}}{S_{x,y(MSF257\rightarrow MSF277)}} \tag{5}$$

The transfer matrix elements can be obtained from a *MAD* simulation of the beam line, using the quadrupole settings given in Table 1. They are given for the transfer from MSF257 to MSF267 and

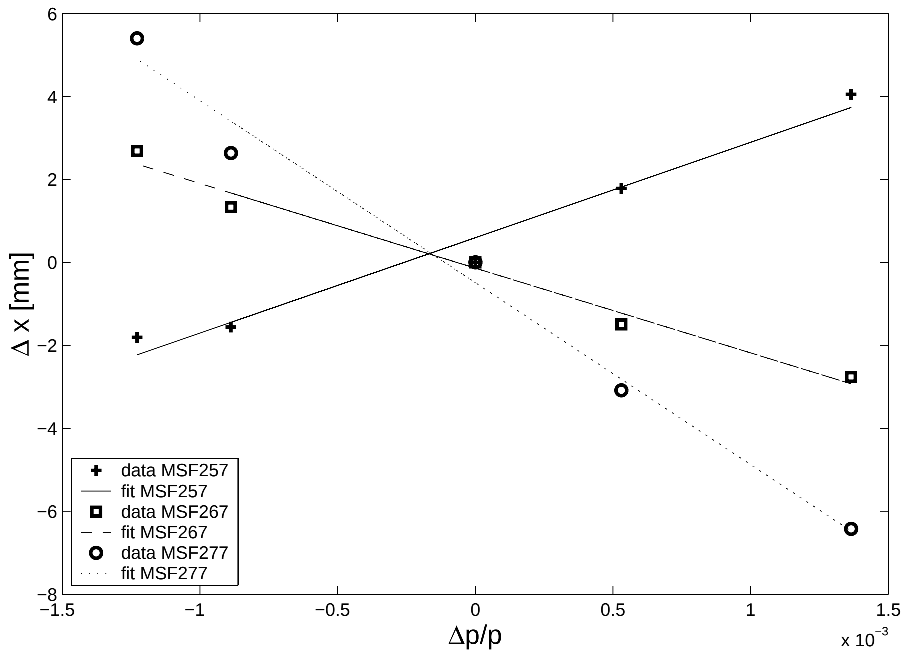

Figure 1: Horizontal displacement of the beam center versus $\Delta p/p$ at MSF257, MSF267 and MSF277. The slope of a linear fitted line yields the dispersion.

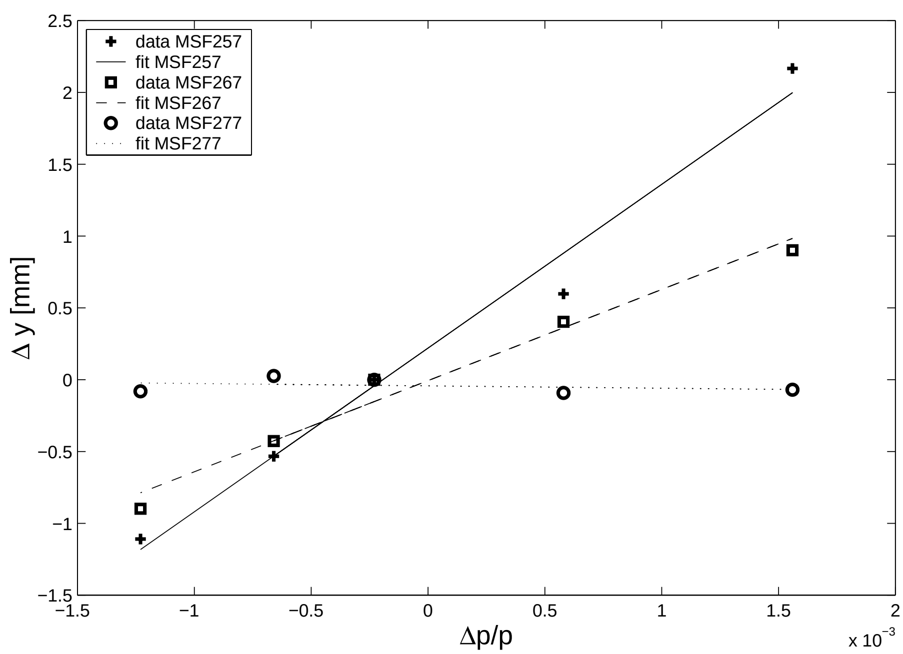

Figure 2: Vertical displacement of the beam center versus $\Delta p/p$ at MSF257, MSF267 and MSF277. The slope of a linear fitted line yields the dispersion. Note, that the sign of the vertical dispersion has been flipped for the further analysis.

	MSF257 → MSF267	MSF257 → MSF277
C_x	1.16741	0.313584
S_x	11.8364	13.3184
C_y	-0.371737	-1.53518
S_y	23.3442	33.6078

Table 6: Elements of the transfer matrices between the TT2 SEM monitors.

from MSF257 to MSF277 in Table 6.

Using these matrix elements and the measured dispersion from Table 5, and averaging the results from equations (4) and (5), we obtain for D' at the location of MSF257:

$$\boxed{D'_x = -0.390,\, D'_y = -0.048}$$

Using this as well as the figures from Table 5, we have a full set of D and D' in both planes at the location of MSF257. We have used again *MAD* to transport these back to the beginning of the line. The results are given in Table 7.

location	D_x [m]	D'_x	D_y [m]	D'_y
Entry TT2	4.68	0.47	-0.28	0.00

Table 7: Initial D and D' at the beginning of the TT2 line.

4 Summary

The optical parameters at the entry of TT2 quadrupole QFO105 derived from the 2003 measurements with an Indium ion beam are summarised in Table 8. The average of the values obtained from measurements in TT2 and TT10 are used. For the sake of completeness the optical parameters at the TT2 entry derived from measurements performed in 1998 [2] using Lead ions are also reported in this table. The values from reference [2] have been re-calibrated using a revised procedure to convert quadrupole currents into gradients [5]. The Twiss parameters and dispersion measured this year for an Indium ion beam are consistent with those measured in 1998 for a Lead ion beam.

	Indium (2003)		Lead (1998)	
	Horizontal	Vertical	Horizontal	Vertical
β [m]	25.49	6.54	26.42	5.72
α	-2.37	0.72	-2.35	0.31
D [m]	4.68	-0.28	3.63	-0.48
D'	0.47	0.00	0.40	0.03

Table 8: Summary of Twiss parameters and dispersion at the entry of TT2 derived from the 2003 measurements with indium ions and the 1998 measurements with lead ions.

References

[1] G. Arduini, M. Giovannozzi, K. Hanke, J.-Y. Hémery, M. Martini, *MAD and BeamOptics Description of the TT2/TT10 Transfer Lines, Part I: Optics without Emittance Exchange Insertion*, CERN-PS-Note 98-14 (CA) and CERN-SL-Note 98-040 (OP) (1998).

[2] 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 Fixed-Target Lead Ion Beam*, CERN-SL-Note 99-018(MD) and CERN-PS-Note 99-009(CA).

[3] G. Arduini, T. Bohl, H. Burkhardt, S. Hancock, D. Manglunki, M. Martini, F. Pedersen, U. Wehrle, *Indium Run 2003: Transition Crossing in PS?*, CERN AB-Note-2003-034(RF) (2003).

[4] A.-S. Müller, *Description of Beam-Matter Interaction in the Covariance Matrix Formalism - Application to Modification of Emittance and Twiss Parameters*, CERN PS-2001-013 (AE).

[5] M. Chassard, R. Coccoli, L. Danloy, J. Delaprison, L. Durieu, G. Granger, J.-Y. Hemery, *Magnet Polynominal Fit*, CERN PS-PA Note 93-30 (1993).