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FITTING ALGORITHMS FOR OPTICAL AND BEAM PARAMETERS IN TRANSFER LINES WITH APPLICATION TO THE LHC INJECTION LINE TI2.

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Abstract

As part of the commissioning with beam of the transfer line TI2 and TI8 from the SPS to the LHC [1], a series of optics measurements has been conducted. The paper presents the results in terms of Twiss parameters (including the dispersion), emittance and momentum spread obtained from the combination of trajectory and beam profile measurements. Profiting from the redundancy of monitors, there is a possibility of applying different fitting algorithms to retrieve beam parameters and to extract information on the optics of the line. The results from the different fit methods applied to the data will be compared with the expected values and cross-checked with independent measurements.

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As part of the commissioning with beam of the transfer line TI2 and TI8 from the SPS to the LHC [1], a series of optics measurements has been conducted. The paper presents the results in terms of Twiss parameters (including the dispersion), emittance and momentum spread obtained from the combination of trajectory and beam profile measurements. Profiting from the redundancy of monitors, there is a possibility of applying different fitting algorithms to retrieve beam parameters and to extract information on the optics of the line. The results from the different fit methods applied to the data will be compared with the expected values and cross-checked with independent measurements.

INTRODUCTION

Minimizing the emittance blow-up in the whole injector chain of the LHC is fundamental in order to reach the highest possible luminosity of the colliding beams. One of the mechanisms that leads to emittance blow-up is the filamentation due to mismatch in the transfer lines [2]. It is very important to have reliable measurements of the beam parameters and a precise knowledge of the optics, to achieve a good matching for the injection in the downstream machine. Dispersion measurements have been done by varying the beam momentum at extraction from the SPS and recording the beam positions at the BPMs in the line, while the Twiss parameters are computed from 2D transverse beam profiles at several BTV monitors equipped with Optical Transition Radiation (OTR) screens. From the dispersion measurements it was also possible to get informations of the machine optics and in particular identify deviations from the model. This paper discusses the algorithms and the applications which have been used during the lines commissioning and presents some of the results, with a special attention to the horizontal plane.

DISPERSION MEASUREMENTS

To compute the values of the dispersion at the beginning of the line, the *Excel application* described in [3] has been used, which is based on the *Passerelle*, a tool to provide access to PS and SPS equipments from Windows platform. The beam position is recorded at the BPMs in TT60-TI2 or TT40-TI8 (respectively 30 and 25) for different values of momentum at extraction, in a range of $\pm 10^{-3}$ around its nominal value. The momentum offset is computed in the application itself by a fit from the pick-ups in the SPS. The dispersion at each BPM is computed from the measurements and then a fit on the initial condition is performed.

In Table 1 are shown the results of the analysis for TI2 and TI8. α is a parameter introduced in the fit for the horizontal plane to take into account calibrations errors of the SPS pick-ups used for the determination of the momentum offset. An overestimation of about 10% is expected. Figure 1 and 2 show the horizontal measured dispersion at the BPMs, together with the theoretical value and the fitted one. For TI8, in addition to a small mismatch, one can see some phase advance shift which may be due to the presence of small errors in the quadrupoles strengths.

Table 1: First analysis with the *Passerelle*

	TI8		TI2		
Horizontal	theor	measur	theor	measur	stdev
$D_0(m)$	-0.33	-0.23	-0.34	-0.25	0.05
D'_0	0.012	7.7e-4	0.013	0.013	0.001
α		1.09		1.04	0.02
Vertical					
$D_0(m)$	0.0	-0.045	0.0	0.08	0.02
D'_0	0.0	1.9e-3	0.0	1.8e-3	0.001

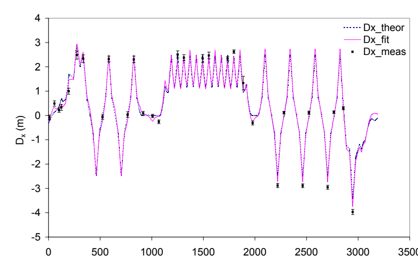

Figure 1: TI2 horizontal dispersion: measured, nominal and fitted values

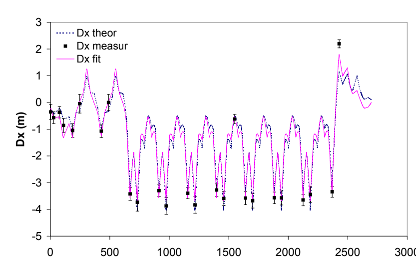

Figure 2: TI8 horizontal dispersion: measured, nominal and fitted values, first analysis with the *Passerelle*

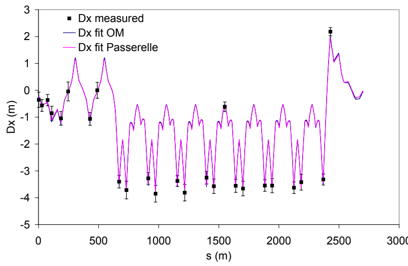

Figure 3: TI8 dispersion, after taking into account the "effective" optics, computed with the *On-Line Model*

OPTICS ERRORS

To investigate the presence of optics errors in the quadrupoles, a fit to the horizontal and vertical measurements was performed with the *On-line Model* [4], using as free parameters the initial dispersion and various sets of quadrupole strength. From the horizontal dispersion it was found that the measurement is well reproduced by adjusting the initial dispersion to values similar to those already found with the *Passerelle* and by increasing the strengths of *MQIF8700M* and *MQID8710M* quadrupole families by a few $\%$, as from Table 2. From Fig. 3 it is now possible to

Table 2: Fit on the arc quadrupole families strengths and initial dispersion results

On-line model results	
D_0	-0.25 m
D'_0	0.0034
Δ (kmqif8700m)	+ 0.15898 e-3
Δ (kmqid8710m)	- 0.57549 e-3

see that the measured dispersion pattern is well reproduced by the fitted initial conditions propagated thought the corrected optics.

TWISS PARAMETERS MEASUREMENTS

The betatronic matching is checked by means of the 9-10 BTV monitors installed in the lines and equipped with Ti, 12 μm thick, OTR screens. The 2D beam profiles are taken at every passage and fits are performed to retrieve α and β at the beginning of the line, the emittance ε and eventually the momentum spread $\delta = dp/p$. We assumeno coupling and that dispersion and optics are known from the previous set of measurements. Emittance and momentum spread are cross-checked with the values measured in the SPS before extraction.

Different fitting methods using a different number of free parameters can be performed. In the 3D method, the standard 3-monitors method is extended to N monitors and a least-square fit is performed to find the best α_0, β_0, ε at the beginning of the line. The overdetermined system to be approximatively solved is:

$$\begin{pmatrix} C_1^2 & -2C_1S_1 & S_1^2 \\ & \dots & \\ & \dots & \\ C_N^2 & -2C_NS_N & S_N^2 \end{pmatrix} \begin{pmatrix} \varepsilon\beta_0 \\ \varepsilon\alpha_0 \\ \varepsilon\gamma_0 \end{pmatrix} = \begin{pmatrix} \sigma_{\beta,1}^2 \\ \dots \\ \dots \\ \sigma_{\beta,N}^2 \end{pmatrix} \quad (1)$$

where $\sigma_{\beta,i}^2 = \sigma_i^2 - D_i^2\delta^2$ is the betatronic beam size, σ_i is the beam size measured at the i-th monitor, D_i is the dispersion, C_i and S_i are the cos– and sin–functions from the beginning of the line to the i-th monitor. The momentum spread δ is given as input from bunch-length measurements before extraction in the SPS.

In the 4D method the free parameters are α_0, β_0, ε and δ and the system to be solved is:

$$\begin{pmatrix} C_1^2 & -2C_1S_1 & S_1^2 & D_1^2 \\ & \dots & & \\ & \dots & & \\ C_N^2 & -2C_NS_N & S_N^2 & D_N^2 \end{pmatrix} \begin{pmatrix} \varepsilon\beta_0 \\ \varepsilon\alpha_0 \\ \varepsilon\gamma_0 \\ \delta^2 \end{pmatrix} = \begin{pmatrix} \sigma_1^2 \\ \dots \\ \dots \\ \sigma_N^2 \end{pmatrix} \quad (2)$$

In the case more then 5 or 6 monitors are available, one could think of evaluating not only α_0, β_0 and ε, but also the dispersion D_0 and its derivative D'_0 at the beginning of the line (5D method) and δ (6D method), following the steps described in [5].

Results of the Twiss Parameters Analysis

The evaluation of the Twiss parameters and emittance can be done in "real time" in the Control Room by a *Java application*, shot by shot. Figure 4 show the typical interface where the user can choose the screens, performs Gaussian fits on the beam profiles, select the 3D or 4D method, enter the momentum spread as input and see the results. On top of that, a further analysis can be done by means of the tools collected in the *On-Line Model* frame [4], also accessible from the Control Room, which allows to perform statistics over several measurements.

In Fig. 5 are shown some of the results from the analysis of the data collected during the commissioning of the lines. For both lines the mismatch in the vertical plane is of a few $\%$, and its measurement is straightforward with the 3D method. In the horizontal plane the mismatch is anyway

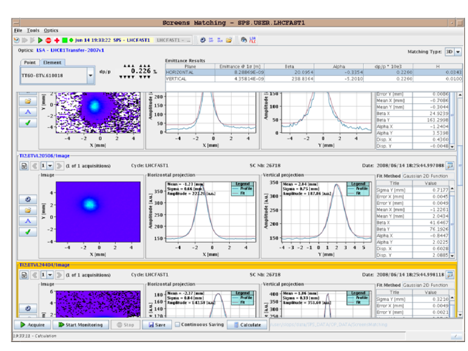

Figure 4: *ScreenMatching* application, to perform Twiss parameters and emittance measurements, shot by shot.

below 10%, but care should be taken in choosing the good set of monitors. A critical parameter for the analysis is δ. The 4D fit usually underestimate it. Its value can be measured from the bunch length before extraction in the SPS, but since there is no logging and it can vary from shot to shot, it is necessary to find a way to overcome this problem. For TI2 the choice has been to use only the 6 screens in low dispersion locations. Further studies are needed to fully profit of the informations provided by all the monitors. For

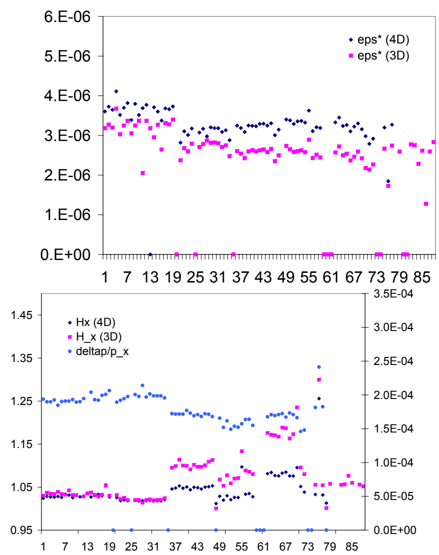

Figure 5: TI8: Horizonal mismatch, δ and normalized emittance. The two curves refer to the 4D and the 3D fit, the last one performed assuming $\delta = 2.5e-4$.

TI8 it was possible to identify the value of $\delta = 2.5e-4$ computed from bunch length measurements. The normalized emittance measured in the SPS with a wire-scanner in a region with high dispersion was $3.5\mu m$, thus consistent with the one measured at the screens. Figure 6 shows the results of a fit over ε, β and over the average beam size measurements offset as a function of δ. All the curves present a discontinuity around a value of $2.7e-4$, close to the value estimated from the measurements in SPS. This can be somehow a way to identify in an automatic way the momentum spread, independently from the measurements in the SPS which can than be used as a cross-check. The computed sigma at the BTVI.81306 is always off by about 15% (in fact the profile at this monitor was very poor and it has been excluded form the fit).

In the 5D and 6D methods, the systems are not well-conditioned, since the TI2 and TI8 lines consist [6] of a first straight section, a FODO lattice with dipoles and another straight section with matching quadrupoles for the injection in the LHC. The beam extracted from the SPS has a very low dispersion and most of it is created in the arcs.

CONCLUSIONS

Different algorithms have been studied for the computation of beam parameters in the transfer lines and their application during the commissioning of the LHC injection lines is here discussed. The *Excel application* based on the *Passerelle*, which has been used since 2002 for dispersion measurements, is a very reliable tool. During the TI2 and TI8 commissioning campaigns a lot of experience has been gained in the measurements of the 2D beam profiles at the OTR screens to retrieve the beam betatronic mismatch. Studies are still ongoing to fully profit of the information provided by all the screens and to combine them with independent measurements of emittance and momentum spread in the SPS before extraction.

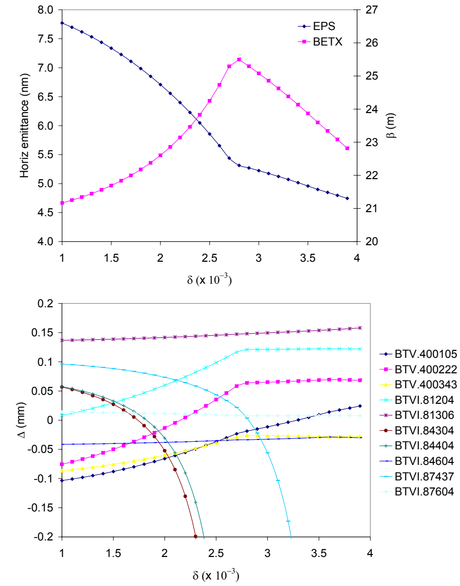

Figure 6: TI8: fitted β and ε (top) and fitted average beam size measurements offset (bottom) as a function of δ.

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