OPTICS MEASUREMENTS AND TRANSFER LINE MATCHING FOR THE SPS INJECTION OF THE CERN MULTI-TURN EXTRACTION BEAM

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Abstract

Dispersion and beam optics measurements were carried out in the transfer line between the CERN PS and SPS for the new Multi-Turn Extraction beam. Since the extraction conditions of the four islands and the core are different and strongly dependent on the non-linear effects used to split the beam in the transverse plane, a special care was taken during the measurement campaigns. Furthermore, an appropriate strategy was devised to minimize the overall optical mismatch at SPS injection. All this led to a new optical configuration that will be presented in the paper.

INTRODUCTION

The new Multi-Turn Extraction (MTE) method [1] to extract beam from the Proton Synchrotron (PS) toward the Super Proton Synchrotron (SPS) is currently under commissioning [2] at CERN. The scheme consists of splitting the beam in the horizontal plane in stable islands and extract them over five consecutive turns. The four islands and the core are created by a series of sextupoles and octupoles which excite the 4^{th} order resonance, a slow bump then brings the beam toward the extraction septum and finally fast kickers extract the beamlets over five turns.

Horizontal trajectories and dispersion are in principle different for each beamlet, due to the non-linear elements and the curve of the kickers, therefore for the MTE it is necessary to perform optics measurements for each of the 5 extracted turns.

Since as a first approximation the parameters of the beam core do not change whether the four islands are created or not, the measurements for the fifth turn can be done in the conventional way [3] in the TT2-TT10 line between the PS and SPS, by extracting the entire beam in one turn, with sextupoles and octupoles switched off.

The trajectories and the dispersion for the islands need to be measured at the first turn in the SPS with Pick-Ups (PUs) for which it is possible to program the gate on each of the five beamlets. The main drawback of this choice, apart from the necessity to have a dedicated cycle in the SPS, is that only a very small energy excursion is allowed for the dispersion measurements.

The profile measurements, to compute the Twiss parameters with the 3-monitors method, have been performed with the OTR screens in TT2-TT10. Since it was not possible to extract one island at the time, an average value has been estimated for the four islands.

From these measurements, two sets of conditions at the beginning of TT2 line have been obtained, one for the core and one for the four islands, assuming for the latter the same dispersion (see next section). A preliminary new optics is proposed for the TT2-TT10 line in order to minimize the overall mismatch at SPS injection.

MEASUREMENTS FOR THE CORE

The optics measurements for the core have been done already in Summer'09, by using the SEMwires in TT2. The parameters, which are summarized in Table 1, are very close to those of the fast-extracted LHC-proton beam at 26 GeV [3], as expected, and have been used for a first matching of the TT2-TT10 line.

At the time of measurement, the beam intensity sharing between the five turns had still to be optimized, so the decision to match the line for the core parameters was justified by its higher intensity with respect of the islands [4]. By the end of the 2009 run a better intensity sharing was achieved, therefore the large mismatch of the islands started to become important [2].

Table 1: Initial conditions for the core. ε_N is the normalized rms emittance, computed at the PS wire-scanners.

	Horizontal	Vertical		Horizontal	Vertical
β_0 (m)	31.39	6.89	D_0 (m)	3.18	-0.125
α_0	-3.11	0.56	D'_0	0.25	0.0014
ε_N (μm)	5.96	5.58			

MEASUREMENTS FOR THE ISLANDS

Dispersion Measurements

The dispersion measurements at the PUs in SPS are usually done by recording the first turn beam position variation as a function of the momentum at PS extraction.

In our case, the MTE beam was suffering of important fluctuations in the extraction conditions (position and energy) which were even amplified by the mismatched and large dispersion in the SPS, giving rise to few mm position variation, for the same nominal extraction energy. In addition, not only because of the intrinsic non-linearity of the islands creation, but also due to the precision of the PUs' gate timing, the allowed momentum variation was very small and was corresponding to a few mm position variation therefore in the noise level. The information on the dispersion and its derivative at the beginning of TT2

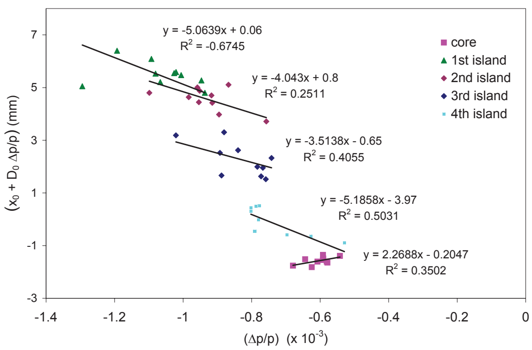

Figure 1: Dispersion measurement for islands and core

line was therefore extracted directly from the correlation of position fluctuations at the PUs.

In particular, knowing that the horizontal position x_i at the i th PU is:

$$x_i = C_i\left(x_0 + D_0\frac{\Delta p}{p}\right) + S_i\left(x_0' + D_0'\frac{\Delta p}{p}\right) + \widetilde{D}_i\left(\frac{\Delta p}{p}\right) \quad (1)$$

where the cos–, sin– functions (C_i, S_i) and the the dispersion created in the line starting with zero initial conditions $\widetilde{D}_i$ at each PU are known, one obtains the three quantities in parenthesis by a fit . The computed momentum offset $(\Delta p/p)$ is fluctuating with an rms spread of about $0.10\,10^{-3}$ for the islands and 0.04 for the core. The position and its derivative (x_0, x_0') at the beginning of TT2 can be computed from the position at the PUs, using, e.g., the software described in [5].

Figure 1 shows the plots of $(x_0 + D_0\,\Delta p/p)$ as a function of $(\Delta p/p)$ for the five turns and the interpolating line with intercept x_0, whose slope represents the dispersion D_0 at the beginning of TT2. A similar analysis is done to obtain the derivative D_0'.

Finally, the momentum offset computed from the fit (Eq. 1) in the horizontal plane is used in the computation of the vertical dispersion. From Table 2 one notes that all the five turns have the same vertical dispersion. In the horizontal plane, the dispersion for the four islands is quite similar, while the measurements for the core are in fair agreement with the results presented in Table 1.

Table 2: Initial conditions for the islands

	Horizontal		Vertical	
	D_0 (m)	D_0'	D_0 (m)	D_0'
1^{st} island	-5.06	-0.42	-0.128	0.0017
2^{nd} island	-4.04	-0.33	-0.126	0.0012
3^{rd} island	-3.51	-0.36	-0.129	0.0019
4^{th} island	-5.18	-0.56	-0.131	0.0020
core	2.27	0.18	-0.124	0.0024

Twiss measurements

To obtain the Twiss parameters at the beginning of the transfer line, profile measurements have been taken at the OTR screens in TT2-TT10. Since it is not possible to extract one island at a time, the image on the screen represents the sum of the four profiles (the core was not extracted) and in general is not a Gaussian, since the islands differ both in dispersion and in trajectory. An rms beam size can be calculated and, with the assumption that the islands have the same twiss parameters and intensity, it is:

$$\sigma_{tot}^2 = \frac{1}{4}\sum_{i=1}^{4}\sigma_i^2 = \frac{1}{4}\sum_{i=1}^{4}\left(\varepsilon\beta + D_i^2\delta^2\right) = \varepsilon\beta + \frac{1}{4}\sum_{i=1}^{4}D_i^2\delta^2$$

Twiss parameters, and beam emittance, are computed using three or more available screens and are reported in Table 3, together with the average dispersion. The very large spread in the acquisitions leads to a large error-bar in the determination of emittance (± 0.7 μm) and beta function (± 10 m). In the vertical plane the fluctuations are smaller. Figure 2 shows the beam size at the OTR screens and the fitted beam envelope in TT2-TT10.

Table 3: Initial conditions for the islands.

	Horizontal	Vertical		Horizontal	Vertical
β_0 (m)	55.06	6.64	D_0 (m)	-4.45	-0.128
α_0	-5.30	0.25	D_0'	-0.42	0.0014
ε_N μm	7.44	4.00			

MATCHING

Since the four islands account for the 80% of the beam, the idea for computing the new optics is to give more weight to the matching quality of the islands. The initial and the new mismatch parameters for the islands and the core are reported in Table 4. H is the betatronic mismatch:

$$H = \frac{1}{2}\left[\frac{\beta_t}{\overline{\beta}} + \left(\alpha_t - \overline{\alpha}\frac{\beta_t}{\overline{\beta}}\right)^2\frac{\overline{\beta}}{\beta_t} + \frac{\overline{\beta}}{\beta_t}\right]$$

and J is the dispersion mismatch:

$$J = 1 + \frac{(\overline{D} - D_t)^2 + \left[(\overline{D'} - D_t')\beta_t + (\overline{D} - D_t)\alpha_t\right]^2}{2\varepsilon\beta_t}\delta^2$$

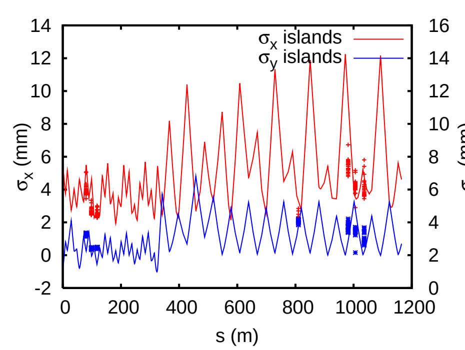

Figure 2: Horizontal and vertical beam rms size at the screens and from the fit.

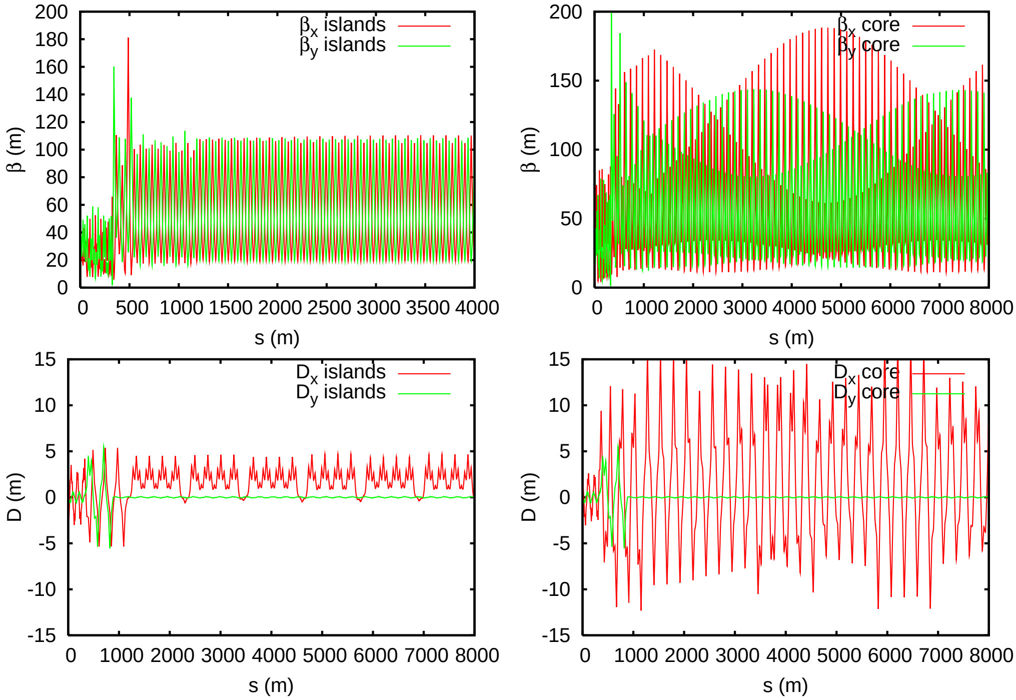

Figure 3: New optics for the islands (Left) and the core (Right)

where β_t, α_t, D_t and D'_t are the theoretical values, $\overline{\beta}$, $\overline{\alpha}$, $\overline{D}$ and $\overline{D'}$ are the measured one and δ is the rms momentum spread. One should note that the core is now mismatched in favor of the islands. As from Table 5, the overall beam matching is improved if one considers the "total" mismatch factors, as a weighted average of the core and islands mismatch $H_{tot} = 0.20H_{core} + 0.80H_{isl}$ and $J_{tot} = 0.20J_{core} + 0.80J_{isl}$.

Table 4: Mismatch factors at injection in the SPS before and after the new matching

	Initial		Final	
Core	Horizontal	Vertical	Horizontal	Vertical
H	1	1	1.16	1.04
J	1	1	1.12	1.00
Islands	Horizontal	Vertical	Horizontal	Vertical
H	1.17	1.04	1.00	1.00
J	1.18	1.00	1.00	1.00

Table 5: Total mismatch before and after the matching

	Initial		Final	
	Horizontal	Vertical	Horizontal	Vertical
H_{tot}	1.14	1.04	1.03	1.01
J_{tot}	1.14	1.00	1.02	1.00

Figure 3 shows the β–functions and the dispersion for the islands and for the core. In the new optics the fast kickers DFA242 and DFA254 in TT2, which are used to correct the island trajectories [5], still have a large enough relative phase advance of 49.5^o for the island optics and 43.7^o for the core (the optimum value would be 60^o).

CONCLUSIONS

Optics measurements have been performed for the transfer of the MTE beam from the PS and SPS, in order to define a new optics for the TT2-TT10 line. Since the core and the islands have different extraction conditions, the choice to match the island parameters at injection in the SPS leads to a configurations in which the core has more than a 10% mismatch in the ring, but in which the overall mismatch (weighted sum of island and core mismatch) is minimized. Another matching solution, which is under study is to distribute the mismatch evenly between the islands and the core, e.g., for aperture reasons.

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