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Trajectory Correction in the Transfer Line TT2-TT10 for the Continuous Transfer (CT)

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Abstract

A new scheme for the trajectory correction in the TT2-TT10 transfer line for the Continuous Transfer (CT) extraction from the PS to the SPS has been developed together with a new software application, PS-CT-Check. In this note the algorithm, the software, and the results of the tests performed during the 2007 run are summarized. The PS-CT-Check user's manual is also provided. The scheme, with minor modifications, will be applied to the new Multi-Turn Extraction (MTE).

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1 Introduction

The Continuous Transfer (CT) is a well-established technique used to extract from the PS to the SPS beams for the fixed-target and CNGS physics. During the CT the horizontal tune is moved close to the quarter integer resonance, $Q_x = 6.25$. The beam is then deflected (through a combination of slow and fast bumps) across an electrostatic septum, that is used to shave off the outer horizontal part of the beam in four subsequent turns. The number of turns is a consequence of the chosen fractional part of the tune, that makes the horizontal phase space rotating by 90° turn by turn, as shown in Fig. 1. To jump beyond the electrostatic septum the central part needs an addition single-turn fast kick. The deflection imparted by the electrostatic septum is such that the five slices enter in the downstream magnetic septum to be eventually ejected from the PS into the transfer line TT2/TT10.

As the beam shaving is optimized in terms of the slice intensities (they have to be equal to the 20% of the total intensity in order to avoid transient effects in the SPS), the extracted slices have unavoidably different contours and centroids [1]. This in turn generates slice-dependent horizontal oscillations in the transfer line. If not corrected, they would induce vertical oscillations in the SPS (because of the emittance exchange insertion in TT10) and eventually a vertical emittance blow up after filamentation.

The present correction scheme makes use of “Automatic Beam Steering” (ABS) software [2], that centers the average beam centroid over the five turns by means of the three bending magnets BHZ117/147/167 of TT2. The difference between the centroids of each single slice is instead corrected by means of two fast kickers,

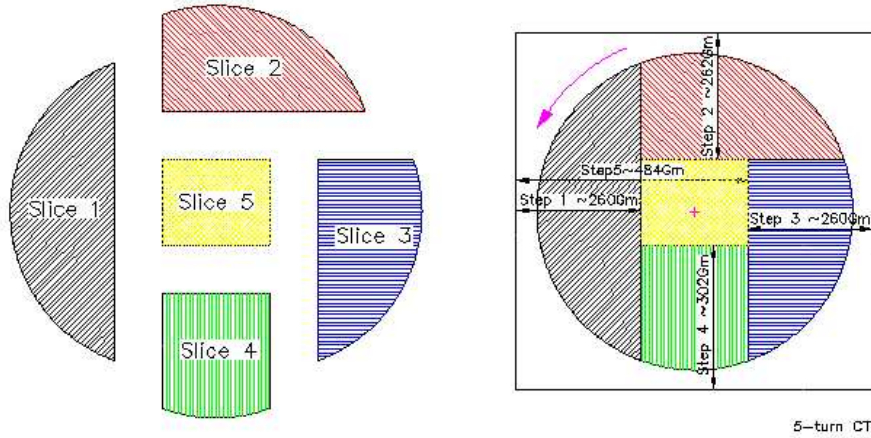


Figure 1: Sketch of the horizontal phase space shaving performed by the electrostatic septum when $Q_x = 6.25$.

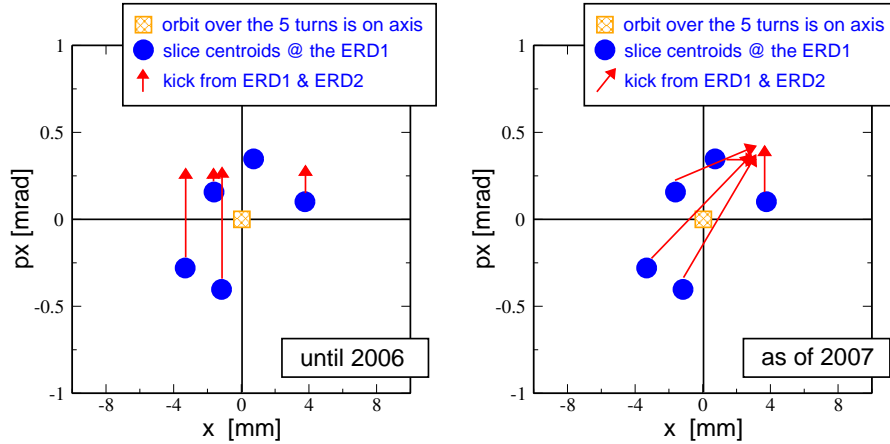


Figure 2: Sketch of the horizontal position and angle of the five slices at the entrance of the first ERD. After the ABS correction, only the “global” trajectory (averaged over the five slices) is centered. Left: with two neighboring kickers (until 2006) the correction could be performed on the angle only (vertical arrows). Right: with the second kicker displaced (as of 2007), a further correction in position is possible. Note that the arrows (kicker strength) points always upwards as only positive voltages can be imparted.

called “Emittance Reduction Dipoles” (ERDs)¹, capable to impart a turn-by-turn variable deflection. This scheme suffers from two main limitations. Firstly, until 2006 the two ERDs were placed 2 m apart with almost zero phase advance, hence imparting a correction in the angle p_x only (vertical arrows in Fig. 2). Secondly they can provide a positive voltage only (in the left plot of Fig. 2 the vertical arrows point upwards). The turn-by-turn kicker voltages have been so far set by trial and error with the aim of reducing the vertical oscillations in the SPS during the first five turns of injection. Because of the vertical filamentation, the slice having the largest oscillation defines the beam emittance, whose blow up scales with the square of the initial vertical offset².

During the 2006/2007 shutdown the second ERD has been moved 22 m downstream (corresponding to an horizontal phase advance between the two kickers of about 62 degrees for the CT optics). Such a modification was implemented in the framework of the Multi-Turn Extraction (MTE) project [3]. This displacement allows a correction both in angle p_x and in position x (the arrows in the right plot of Fig. 2 are no longer vertical) and has triggered the development of a new scheme for a more effective correction. This scheme is described in Sec. 3.

¹In the PS control system they are better known as DFAs.

²Typical value recorded during the 2006 run was of about 6 mm.

The new software application **PS-CT-Check** has been developed and included in the steering program **YASP** to measure the vertical trajectories of the individual slices in the SPS first, and to infer from these data the best corrector setting for the ERDs. The global steering downstream the second ERD (namely in TT10) is carried out separately by means of the **MICADO** application [4]. User's manual and features are described in the Appendix A and B respectively.

Both the algorithm and the **PS-CT-Check** application have been tested during the 2007 run. Results are reported in Sec. 4. It is worthwhile mentioning that, even on paper, the correction cannot be perfect because of some intrinsic characteristics of the ERDs, outlined in Sec. 2.

This scheme will be applied to the new Multi-Turn Extraction (MTE). With this new scheme the electrostatic septum used to slice the beam in five turns will be no longer necessary, as five islands will be generated and then separated by means of non-linear elements. One of the main advantages of this technique is that the extracted islands will have the same intensity, emittance and optical parameters. The difference among the islands centroids is also expected to be smaller than in the CT. This persistent spread is a consequence of the inevitable dipole feed-down field in the quadrupoles (the island trajectories are always off-centered), which perturbs the island closed orbits (both the slow and the fast bumps are closed for the beam core only)³. The applicability of the new corrector scheme to the MTE is discussed in Sec. 5.

2 The “Emittance Reduction Dipole” (ERD) kickers

The ERDs consist of two independent kickers⁴. The first one, called DFA242, provides a constant (pedestal) voltage for a duration of $2.1 \mu\text{s}$ (corresponding to one PS turn at $14 \text{ GeV}/c$), as shown in Fig. 3. The start time can be set arbitrarily, hence leaving the freedom to choose any of the five slices to be kicked. Usually the DFA242 is powered at the passage of the last slice, as its extraction conditions differ largely from those of the four slices, requiring usually a larger correction.

The second ERD, called DFA254, is able to impart a turn-by-turn variable strength during the five extraction turns. As shown in Fig. 4 its *staircase* waveform is such that turn by turn the voltage can either increase or remain constant.

Until the 2006 run, the second ERD was called DFA243, being placed next to the DFA242 (see upper picture of Fig. 5). The vicinity of the two kickers posed some limitations in the trajectory correction, as discussed in the Introduction. For

³In the PS the above feed-down field is actually generated by the quadrupolar components of the main combined-function dipoles magnets, rather than by quadrupoles.

⁴Note that once the CT will be replaced by the MTE, the kicker will be upgraded and some of features and parameters listed in this section will not be valid anymore (see Sec. 5).

Name	ERD1	ERD2
Element	DFA242	DFA254
Kicker type	pedestal	staircase
Mechanical apertures [h, v] (cm)	14.8, 5.35	14.8, 5.35
Magnetic apertures [h, v] (cm)	14.8, 5.35	14.8, 5.35
Deflection plane	horizontal	horizontal
U max PFN (kV)	30	30
Magnet I max (A)	500	1140
Generator impedance (Ω)	25	25
Magnet L (μ H)	10.35	2.49
Magnet L_{eff} (μ H)	9.24	2.31
Max air field (Gauss)	234.8	267.6
Effective length (cm)	66.5	66.5
Max integral Bdl (Gauss m)	156.1	178.0
Max deflecting angle at 14 GeV/c (mrad)	0.334	0.381
Rise/Fall time (5-95)% (ns)	700	700
Flattop (μ s)	2.35	12.6

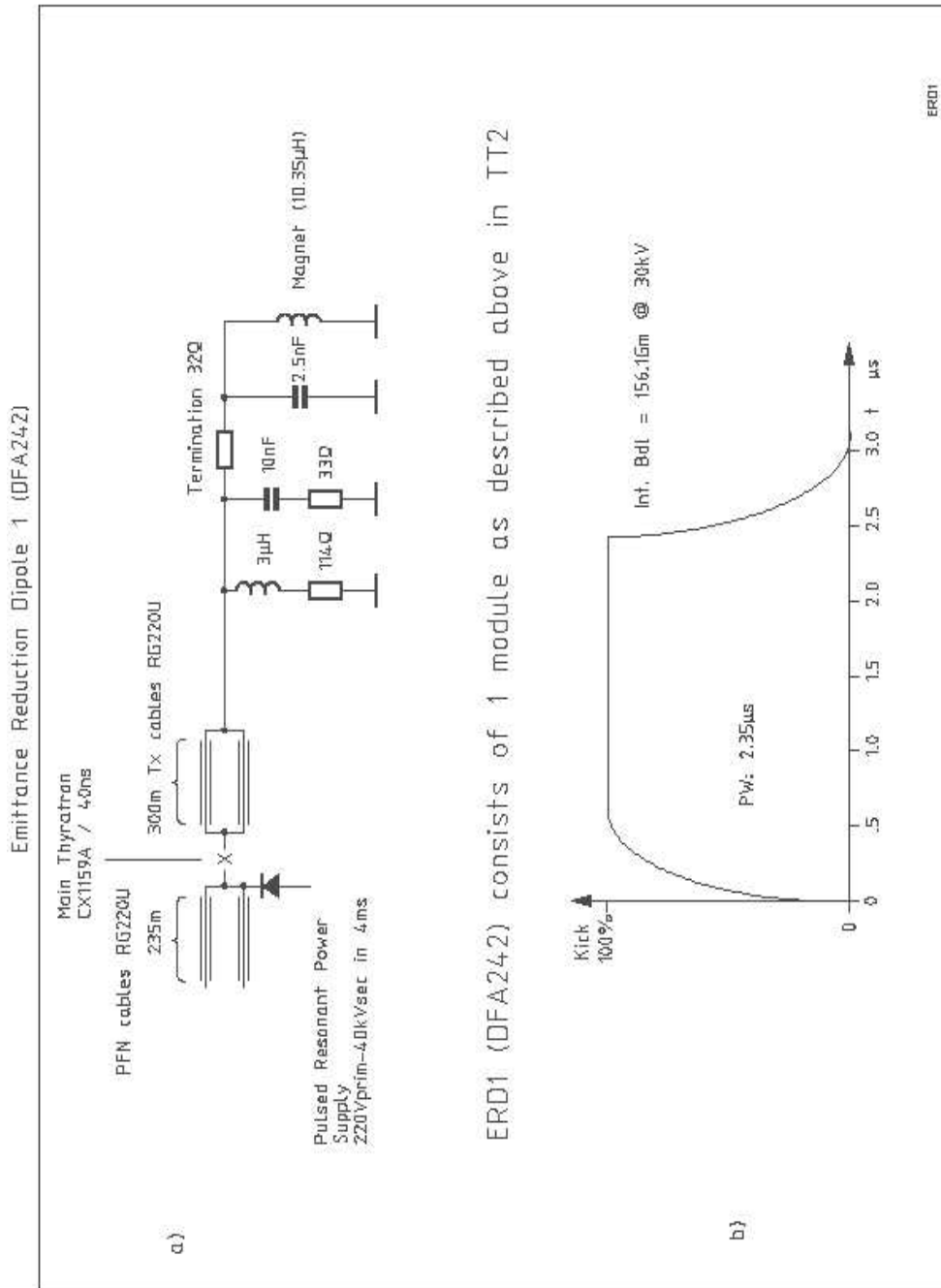
Table 1: Parameter list of the two ERD kickers installed in the TT2 transfer line.

this reason during the 2006/2007 shutdown the second ERD has been displaced downstream. The most effective correction would require a phase advance between the two kickers of 90° , corresponding to a distance of about 33 m. Two main considerations led to a different solution. First of all the vertical beam clearance would have been reduced, because of the larger vertical beta function at the new position, and because of the vertical kicker full aperture (5.35 cm), which is smaller than the diameter of the existing vacuum chamber (13 cm). Second, the new position would have required a new cabling. A trade off was hence found by displacing the second ERD by 22 m, corresponding to a phase advance of about 62° . The kicker has been then renamed as DFA254 in order to keep a consistent nomenclature in the transfer line, as the nearest downstream element is the quadrupole QFO255 (see lower part of Fig. 5). The main kicker parameters are listed in Tab. 1.

The conversion relations implemented in the MAD-X [5] scripts to compute the integrated kick strengths starting from the voltage are

$$K_{DFA242} = \frac{V_{DFA242}}{30} \frac{0.2998 \cdot 0.01561}{pc}, \quad (1)$$

$$K_{DFA254} = \frac{V_{DFA254}}{30} \frac{0.2998 \cdot 0.01780}{pc}, \quad (2)$$



ERD1 (DFA242) consists of 1 module as described above in TT2

Figure 3: Schematic circuit diagram of the first (pedestal) ERD kicker, DFA242. As of 2009 the flat top will be extended to $10.5 \mu\text{s}$, corresponding to five PS turns at $14 \text{ GeV}/c$.

Continuous Transfer Staircase Bumper Configuration

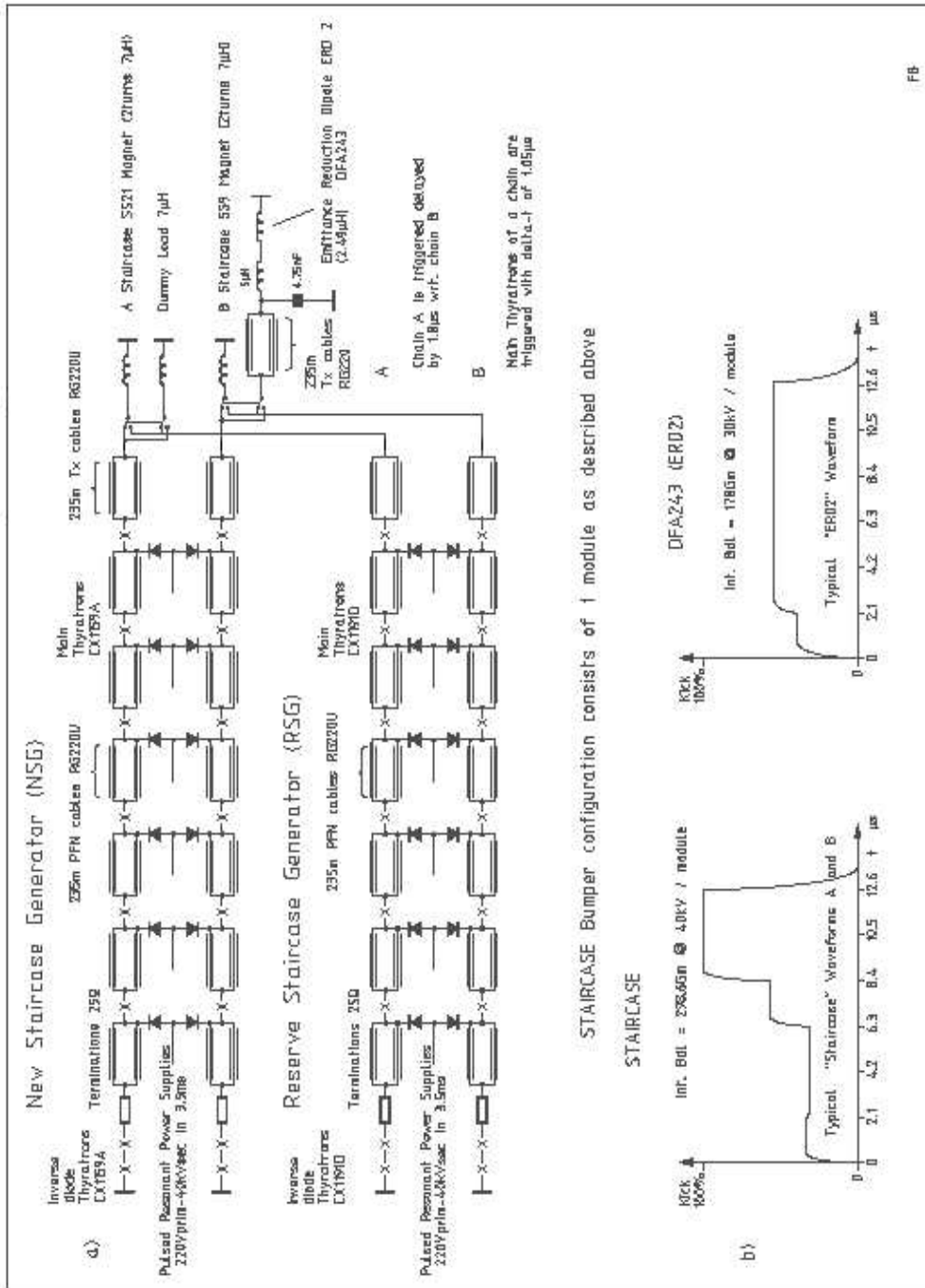


Figure 4: Schematic circuit diagram of the second ERD kicker, DFA254 (ex DFA243).

where the units of K, V and pc are rad, V and GeV respectively.

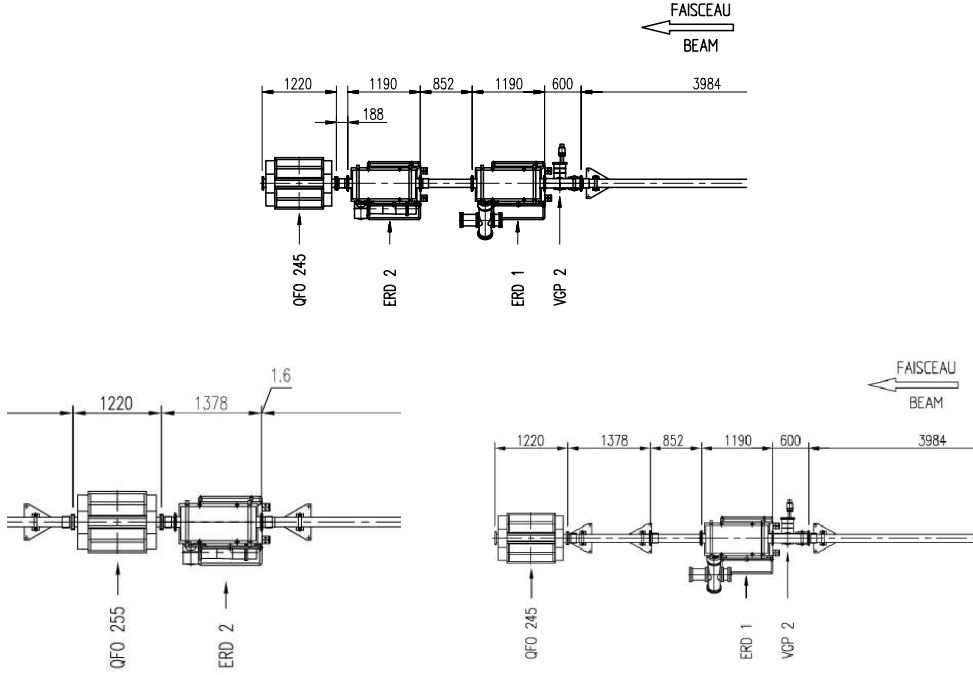


Figure 5: Former ERD layout, with the two consecutive kickers (top), and current configuration with the second kicker displaced of 22 m downstream, next to the quadrupole QFO255 (bottom).

3 The correction algorithm

The basic ingredient for the trajectory correction in the TT2/TT10 transfer line is the knowledge of the horizontal position and angle of each one of the five slice at the beginning of TT2, $\vec{P}_i = (x_i, p_{x,i})$ where $1 \leq i \leq 5$. The lack of broad-band beam position monitors (BPMs) able to acquire data turn by turn, neither in the PS extraction channel nor in the transfer line, renders impossible to measure directly \vec{P}_i , that hence have to be inferred from five separate measurements of the first-turn vertical trajectory in the SPS. A new module of the YASP program called PS-CT-check acquires the trajectories of the five slices during their first turn (See Appendix A for the details). A second MAD-X script generates a random distribution of initial conditions that are tracked along the transfer line down to the second SPS sector. For each slice, the initial condition (x, p_x) minimizing the difference (in L^2 norm) between the measured vertical trajectory and the one obtained from tracking is stored as \vec{P}_i .

Different extraction conditions (or equivalently different slice centroids), if not corrected, will result in different \vec{P}_i . Non-zero \vec{P}_i result in turn in coherent betatron oscillations (horizontally in TT2, vertically in TT10 and in the SPS after the exchange insertion), whose amplitude along the transfer line and inside the SPS is defined by the linear optics and the initial *slice emittance* $\epsilon_{x,i}$, where as usual $1 \leq i \leq 5$. The latter is defined as:

$$\epsilon_{x,i} = \hat{x}_i^2 + \hat{p}_{x,i}^2, \quad \begin{pmatrix} \hat{x}_i \\ \hat{p}_{x,i} \end{pmatrix} = \begin{pmatrix} (\beta_x)^{-1/2} & 0 \\ \alpha_x(\beta_x)^{-1/2} & (\beta_x)^{1/2} \end{pmatrix} \begin{pmatrix} x_i \\ p_{x,i} \end{pmatrix}, \quad (3)$$

where the Twiss parameters at the beginning of TT2, β_x and α_x , can be taken either from the lattice model or from a separate measurement. Ideally $\epsilon_{x,i}$ should be the same and equal to zero for all the five slices. Scope of the ERDs is hence to minimize turn by turn the differences between the five $\epsilon_{x,i}$, whereas a downstream global steering (i.e. constant during the five extraction turns) will minimize the whole oscillation.

A third script computes the five *slice emittances* $\epsilon_{x,i}$ and tracks the initial conditions \vec{P}_i from the beginning of TT2 until the second ERD. The tracking is repeated for all the different ERDs voltages which are compatibles with the kicker characteristics:

- the ERDs can impart positive voltages only;
- the start time of the first (pedestal) ERD is a free parameter but the kick duration is limited to one turn only⁵;
- during the whole cycle the voltage of the second (staircase) ERD can vary from 5 kV to 30 kV and turn by turn it can only increase or remain unchanged⁶.

Given these constraints, for each ERD setting k the routine computes the five positions and angles at the end of the second ERD, $\vec{P}_i(k)$. It then computes the following mean values and RMS spreads,

$$\bar{x}(k) = \frac{1}{5} \sum_{i=1}^5 x_i(k), \quad \bar{p}_x(k) = \frac{1}{5} \sum_{i=1}^5 p_{x,i}(k), \quad (4)$$

$$\delta x(k) = \sqrt{\sum_{i=1}^5 \frac{[x_i(k) - \bar{x}(k)]^2}{5}}, \quad \delta p_x(k) = \sqrt{\sum_{i=1}^5 \frac{[p_{x,i}(k) - \bar{p}_x(k)]^2}{5}}. \quad (5)$$

⁵This limit will be removed in 2008, when the maximum duration will be extended over five turns.

⁶Once the CT will be replaced by the MTE, an additional constraint will be imposed in order to avoid mismatch with the PS kickers, namely the forth and the fifth turns will be kept at the same voltage.

By using the model Twiss parameters β_x^* and α_x^* at the position of the second ERD, the final RMS *beamlet emittances* spread is computed,

$$\delta\epsilon_x(k) = \sqrt{\delta\hat{x}(k)^2 + \delta\hat{p}_x(k)^2}, \quad (6)$$

where

$$\begin{pmatrix} \delta\hat{x}(k) \\ \delta\hat{p}_x(k) \end{pmatrix} = \begin{pmatrix} (\beta_x^*)^{-1/2} & 0 \\ \alpha_x^*(\beta_x^*)^{-1/2} & (\beta_x^*)^{1/2} \end{pmatrix} \begin{pmatrix} \delta x(k) \\ \delta p_x(k) \end{pmatrix}. \quad (7)$$

The ERD setting providing the lowest spread, $\delta\epsilon_x^{min} = \min_k |\delta\epsilon_x(k)|$ is considered the best one and is printed out in a list of seven entries:

- 5 voltage values for the second (staircase) kicker DFA254
- 1 voltage value for the first (pedestal) kicker DFA242
- the turn number (from 1 to 5) in which the DFA242 has to be powered

Note that all the scripts rely on the lattice model, namely on the Twiss parameters (at the beginning of TT2 and at the second ERD), as well as on the transfer matrix (between the ERDs and between the beginning of TT2 and the first ERD). These quantities have been hard-coded and should be replaced in case a new optics is implemented. The ERD setting used during the initial YASP acquisition needs also to be provided. This has not been hard-coded as it changes often and is given in input to the tracking scripts by the user. It is foreseen to upgrade to routine in order to include a call to the optics database to use the actual optics and setting, hence avoiding any hard-coding and manual input.

It is worthwhile mentioning that the impossibility of changing the voltage polarity and the increasing staircase voltage prevent the correction from being perfect, even on paper. If the extraction conditions of the five slices require an increasing kicker voltage, the staircase kicker may provide an optimum correction, as shown in the left picture of Fig. 6. On the other hand, if a slice, the third for example, is ejected with a \vec{P}_i that would require a voltage lower than the previous ones, the correction can be only partial, as the voltage cannot be reduced. In our example, shown in the right picture of Fig. 6, the voltage is forced to have the same value during the first three turns (which is a trade off between the ideal voltages).

4 Results during the 2007 run

Before implementing the correction scripts in the YASP program a series of tests were carried out during the 2007 run.

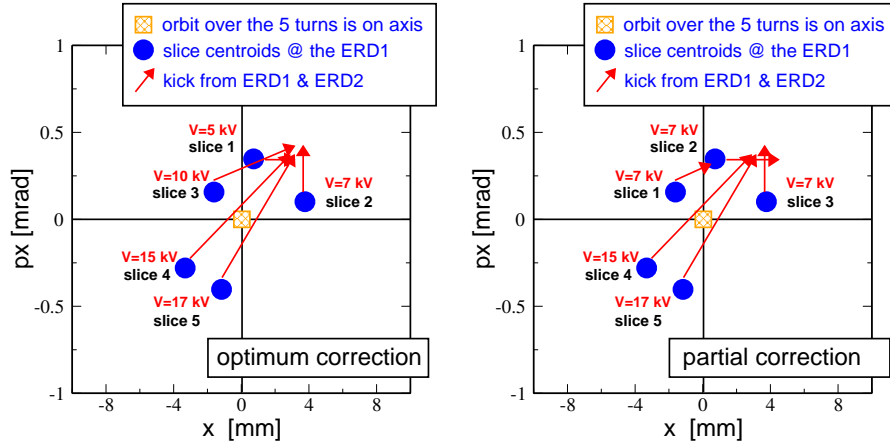


Figure 6: Sketch of the horizontal position and angle of the five slices at the entrance of the first ERD. After the ABS correction, only the “global” trajectory (averaged over the five slices) is centered. Left: the extraction conditions are suitable for an optimized correction, namely the voltages requested from the staircase ERD are increasing. Right: an example of unoptimized correction. The third slice would require a voltage lower than the one requested by the first one. Being this not possible, the correction is partial.

The first one was performed on May 25 with a low-intensity SFTPRO beam. The first-turn vertical trajectory in the SPS was recorded for each slice after shifting the BPM gates ⁷. Being this the first attempt of correction, the two ERDs were still turned off and an injection loss of about 11% was observed. As shown in the

Parameter	value
DFA242 voltage (kV)	18.5
DFA242 start (turn)	5 th
DFA254 voltage turn # 1 (kV)	13.2
DFA254 voltage turn # 2 (kV)	13.2
DFA254 voltage turn # 3 (kV)	13.2
DFA254 voltage turn # 4 (kV)	17.3
DFA254 voltage turn # 5 (kV)	17.3

Table 2: ERD correctors setting computed on May 25 2007 for a low-intensity SFTPRO cycle.

⁷The setting up of the BPM gates is discussed in APPENDIX A

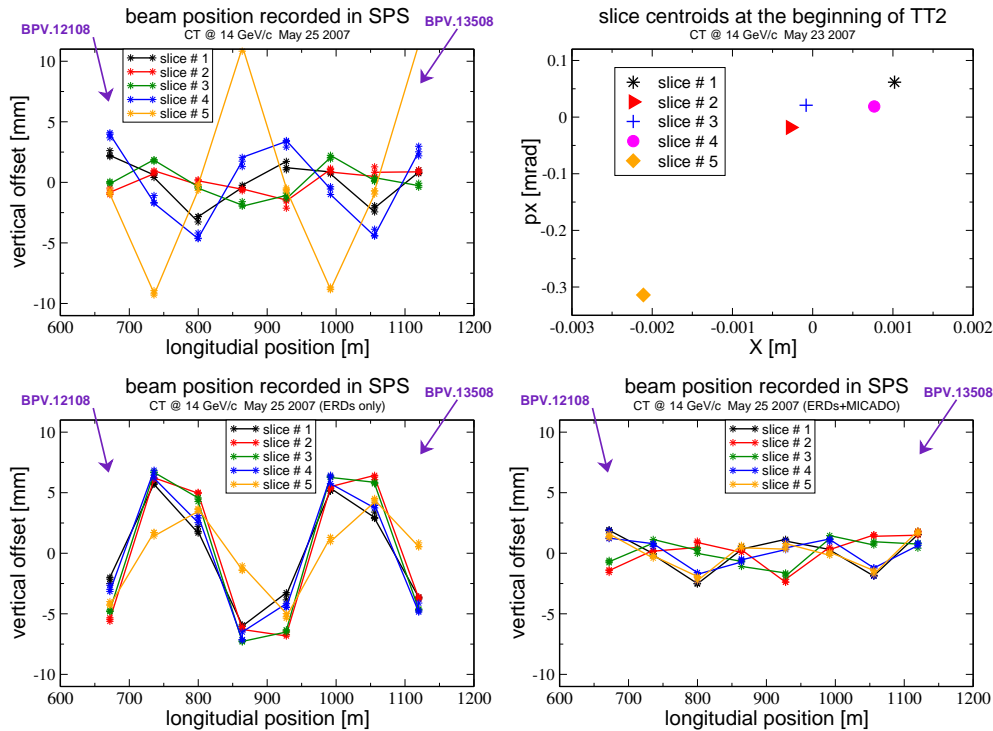


Figure 7: Measurement and correction of May 25 2007: measured first-turn vertical trajectories in the first sector of the SPS with the ERDs turned off (upper left); horizontal initial conditions at the beginning of TT2 (upper right); measured first-turn trajectory after correction with the ERDs only (lower left) and after an additional global MICADO steering (lower right).

upper left plot of Fig. 7 the loss was mostly due to the large vertical oscillation of the last slice (~ 10 mm). From those data the initial conditions at the beginning of TT2 were determined (see upper right plot of Fig. 7). The correction routine was then launched and the setting listed in Tab. 2 was found and implemented. The results are shown in the lower left plot of Fig. 7. It is clearly seen that the spread between the five slices was largely reduced. In order to remove the global oscillation, the MICADO application was run. The final results are shown in the lower right plot of Fig. 7. Note that the persistent oscillation of about 2 mm could not be removed because the third slice would have required a voltage lower than the first two. After correction, injection losses dropped to about 2%.

A second test was performed during a high-intensity operation on June 29, when a major change in the PS extraction setting needed to be carried out. With the ERDs setting of May 25 the slices showed still a good homogeneity except for the last one (see left plot of Fig. 8). The values computed by the correction routine

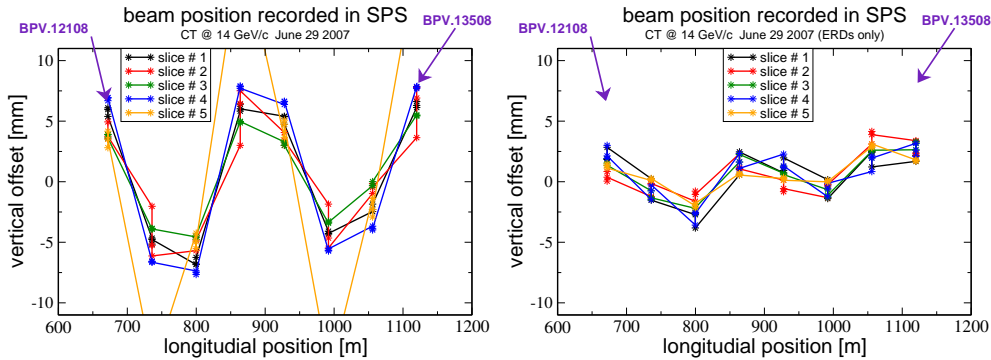


Figure 8: Measurement and correction of June 29 2007: measured first-turn vertical trajectories in the first sector of the SPS with the ERDs turned off (left) and after correction with the ERDs (right).

Parameter	value
DFA242 voltage (kV)	15.9
DFA242 start (turn)	5 th
DFA254 voltage turn # 1 (kV)	11.5
DFA254 voltage turn # 2 (kV)	11.5
DFA254 voltage turn # 3 (kV)	11.5
DFA254 voltage turn # 4 (kV)	16.5
DFA254 voltage turn # 5 (kV)	16.5

Table 3: ERD correctors setting computed on June 29 2007 for a high-intensity SFTPRO cycle.

are listed in Tab. 3 and the results of their implementation is shown in the right plot of Fig. 8. Temporary problems with the BPMs polarity hampered a further global correction through the MICADO steering program⁸. After correction, injection losses went down again to about 2%.

After these successful tests the YASP program was upgraded in order to carry out automatically both the first-turn acquisition (i.e. without the manual BPM scan) and the computation of a new corrector setting. This new complete module has been used for the trajectory correction of the CNGS beam, whose results are

⁸Two times during the 2007 run the BPMs front-end computers reported the beam position along the transfer line with wrong sign, making the MICADO correction algorithm diverge. Even if not understood, this problem no longer occurred during the rest of the run.

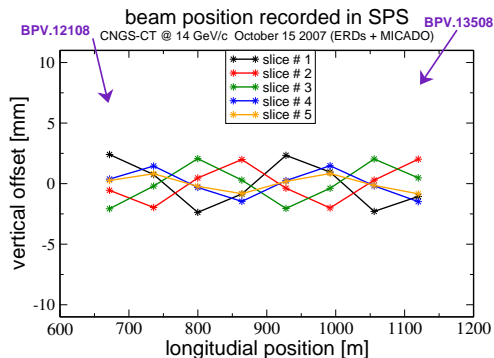


Figure 9: Measurement and correction of October 15 2007: measured first-turn vertical trajectories in the first sector of the SPS after correction with the ERDs.

shown in Fig. 9. Injection losses remained below 3%.

5 Outlook: from CT to MTE

The MTE [3] shall replace the present CT after commissioning in 2008. The five slices will be no longer produced by shaving the beam onto the electrostatic septum. Instead five beamlets will be generated by trapping the beam in stable islands of the fourth-order resonance excited by two pairs of sextupoles and octupoles. One of the main advantages of this new scheme is that the first four beamlets have exactly the same optical properties and the spread between the five extraction conditions is expected to be smaller than in the CT. Since the islands execute large horizontal oscillations for thousands of turns, they experience an island-dependent dipole field due to the feed-down from the quadrupoles, which prevents the first four beamlets to leave the PS with exactly the same conditions \vec{P}_i ⁹. To improve further the beam quality in the SPS and to match the specifications of the PS kickers, the ERDs in TT2 will be upgraded, and the correction routine modified accordingly. The modifications can be summarized as follows.

- As of 2008 the voltage of the DFA254 during the last two turns will be kept constant in order to avoid mismatch with the two PS kickers used for ejecting the central core during the fifth turn (KFA71/79 and KFA4)¹⁰. The rise time¹¹ of the DFA254 (580 ns presently, 350 ns as of 2009) would not match the ones of the two PS kickers, 70 and 80 ns respectively, and a

⁹We recall that in the PS the above feed-down field is actually generated by the quadrupolar components of the main combined-function dipoles magnets, rather than by quadrupoles.

¹⁰See Ref. [3] for a complete overview of the new extraction kickers.

¹¹In this Section the rise time is always considered as the time needed to change the strength from 10% to 90%. The 5% – 95% rise time is a factor 1.2 longer [3].

difference in voltage between the last two turns could not be applied with the correct timing (given by kickers in the PS ring). This will not affect the correction, since the above PS kickers can be properly adjusted in a way that the fourth and the fifth beamlets have the same extraction conditions.

- As of 2009 the DFA254 rise time will be shortened to 350 ns, which is the same rise time of two new PS kickers (KFA13 and KFA21) that will be installed by 2008 and used to generate a new fast bump in straight section SS16. A third kicker (KFA9) with the same rise time will be installed in the PS ring by 2009 and will be used to improve the bump closure.
- As of 2009 the DFA242 maximum deflecting angle will be halved from 0.0334 mrad to 0.0167 mrad, in order to reduce its rise time to 350 ns.
- As of 2009 also the ERD DFA242 will be operated in a staircase mode.
- As of 2009 the maximum achievable flat top length of both (staircase) ERDs will be of 8.4 μ s, corresponding to four PS turns. The ERDs are expected not to operate during the first of the five turns.

The three upstream bending magnets (BHZ117, BHZ147 and BHZ167), normally used by the ABS, will be included in the computation of the best ERD setting. Once they correct the trajectory of the first island, the ERDs will correct separately the remaining four by using the first island as reference. The combined use of BHZs and ERDs will also allow to minimize the required ERD voltage. The same scheme will be also applied to the standard CT in 2008, when CT and MTE will still cohabit.

6 Conclusion

A new scheme for an automatic trajectory correction in the transfer line TT2-TT10 for the CT has been developed and successfully tested during the 2007 run. The algorithm has been implemented in the steering program YASP. Being the corrector setting highly dependent on the PS extraction conditions, the program has to be launched every time the PS extraction is modified. For the MTE some parameters in the algorithm need to be changed. The code description as well as the user manual are provided together with the results of the 2007 tests.

7 Acknowledgments

We are grateful to L. Sermeus for providing all the details concerning the ERDs, to O. E. Berrig for his support in modeling the SPS and TT2-TT10 transfer line, and to the OP group for its support in testing and implementing the new scheme.

A APPENDIX: PS-CT-Check user's manual

Step 1: opening the program

First open the YASP program from the SPS console manager and select the **Fturn** acquisition mode to acquire the first-turn trajectory in the SPS. The PS-CT-Check window is opened from the YASP menu bar entry **Machine special**, as shown in Fig. 10. A new window (shown in Fig. 11) will then pop up. The next step explains how to cross-check the BPM timing and might be skipped after an initial set-up at the beginning of the run.

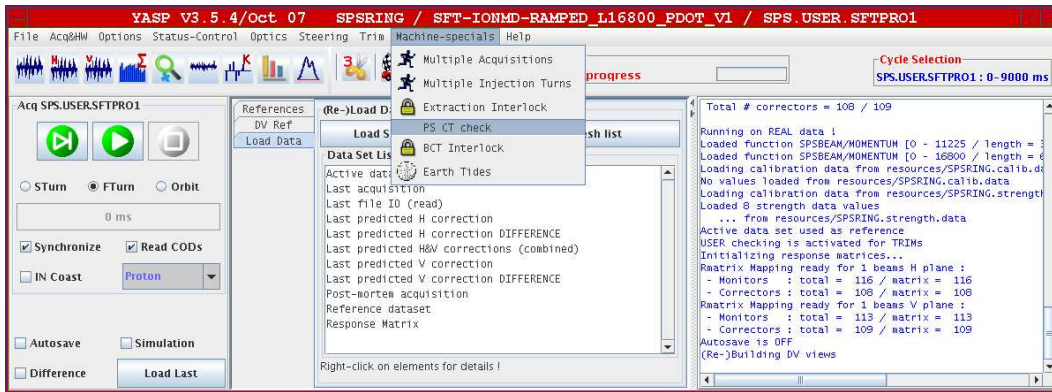


Figure 10: Snapshot of the main YASP window with the entry launching the PS-CT-Check module.

Step 2: setting the BPM delays

The SPS BPM system is composed of six independent blocks corresponding to the six SPS sextants. Being the low-level electronics independent, specific delays among the six blocks need to be introduced in order to synchronize the acquisition. The delay system consists of a **First-Turn Delay** and of a **Sampling Delay**. Both need to be specified for each sector and can be displayed, as well as edited, from a separate window (see Fig. 12) to be opened by clicking on the **Acquisition Setting** button in the bar menu entry **Acq&HW**. Values are set by experts and shall be restored at the end of the correction, if the timing is done manually. By skipping this step, namely by trusting the default values displayed in the window of Fig. 12, the default values will be automatically restored.

The following procedure is meant to find the delays that gates the BPMs on each of the five slices, and is usually carried out at the beginning of the machine run only, the timing system being the same during the entire run. As the PS-CT-Check module makes use of data from the first two sectors only, others delays

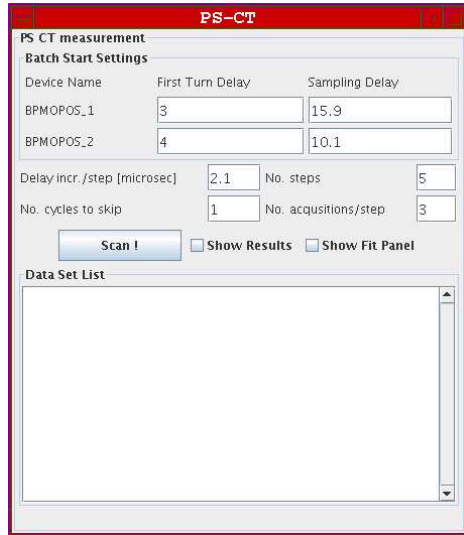


Figure 11: Snapshot of the main PS-CT-Check window.

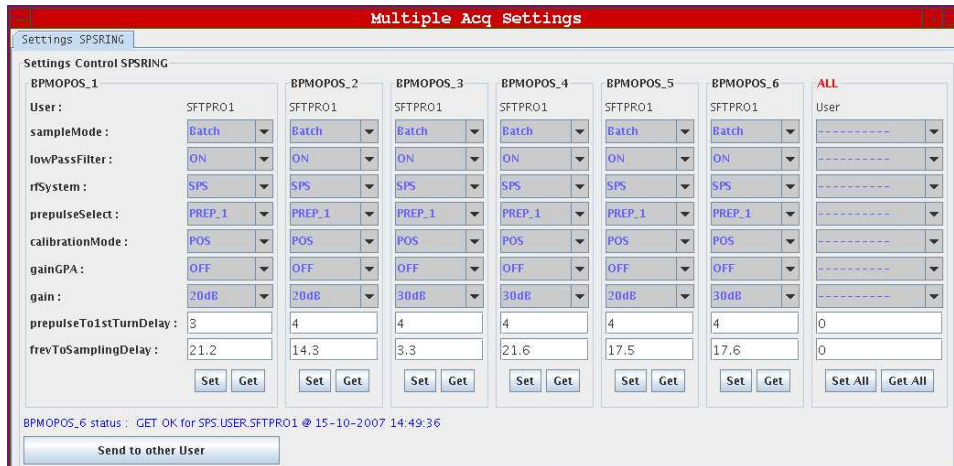


Figure 12: Snapshot of the SPS BPM acquisition setting window. The low-pass filter must be turned off while setting the BPM delays.

may be left unchanged. The Acquisition Setting window has an entry also for the second sector, which is however not used by the correction routine.

- Display the sum signals Σ in the YASP main window, after turning off the low-pass filter in the Acquisition Setting window of Fig. 12.
- Set the right **First-Turn Delay** by looking at the Σ signal: if the turn delay is too small, no signal is visible, since the BPMs are gated before the beam enters the SPS. The right turn delay is hence the first one showing a non-zero Σ signal. Notice that if the signal is well below 1000, also the BPM gain should be increased.

- The **Sampling Delay** is a number between 0 and $23 \mu s$ (the SPS revolution period at $14 \text{ GeV}/c$). The SPS is filled with two PS batches of five $2.1 \mu s$ long slices each. The first batch injected into the SPS is hence $10.5 \mu s$ long. The first step in finding the right sampling delay is to shift by hand its values in order to define the two batch ends, namely two points with zero Σ signal, separated by about $11 \mu s$, between which a non-zero signal is visible (the first PS batch). Once these two extremes are found, shift the smallest one of about $1 \mu s$: this would gate the BPM at the center of the first slice. Notice that even if the BPM gate is of $1 \mu s$, its signal is integrated just before the gate falling edge only. This sampling delay, together with the First-Turn Delay previously obtained shall be inserted in the corresponding PS-CT-Check boxes. The same procedure shall be repeated for the second sextant.
- To cross-check the delays, a LabView[®] application [6], called startMopos, might be used during a test PS-CT-Check acquisition. This application is launched from SPS console manager \rightarrow **SPS Equipment Control** \rightarrow **SPS Beam Instrumentation** \rightarrow **MOPOS Scope Diagnostics**. A window like the one shown in Fig. 13 will pop up. After selecting the right **CYCLE** and monitoring the first sector gate (BA1 SPS) in the **SCOPE** entry, both the sum signal and the BPM gate will be displayed. Once a test acquisition is started, the BPM gate signal shall move along the batch and the user can verify the **Sampling Delay** goodness.



Figure 13: Snapshot of the LabView scope startMopos: in yellow (white in b/w) the sum BPM signal showing the $10.5 \mu s$ long batch, in magenta (gray in b/w) the BPM gate moving from the fourth slice (left) to the fifth slice (right). Note that the **timebase** is here set to $1 \mu s$ per division and the **Trig. Pos** is set to 9×10^6 .

CPS:EJECTION16 - CPS.USER.SFTPRO					
File Edit View References Commands Control Programs					Help
Oct 15 17:39:39 CPS - SFTPRO					
NORMAL view					
KSU	State	CCV	AQN1	Unit	
PE.KFA71	Off	430.4	0.0		
PE2.KFA71	Off	67.0	0.0		
POW-V	Status	CCV	AQN	Unit	
PE.SMH16	0n	15500.00	15497.61	A	
PE.BSW16	0n	660.00	632.01	A	
PE.BSW31	0n	265.00	268.55	A	
PE.QKE16	0n	316.00	300.76	A	
PE.QKE58	Off	0.00	0.00	A	
PR.OCT	Standby		0.18	A	
PR.XCT	Standby		-0.03	A	
PE.QKE16CT25	0n	1960.00	1945.01	A	
PE.QKE16CT73	0n	1950.00	1946.29	A	
POW-V	Status	CCV	AQN	Unit	
PE.SEH31	0n	182.00	180.04	kV	
POW	Status	CCV	AQN	Unit	
PE.BFA21-9	0n	-	-		
PE.BFA21-9S1		7.31	7.07	kV	
PE.BFA21-9S2		9.50	9.34	kV	
PE.BFA21-9S3		8.04	7.98	kV	
PE.BFA21-9S4		12.41	11.73	kV	
PE.BFA21-9S5		31.99	32.32	kV	
PE.BFA21-9S6		32.01	31.67	kV	
PE.BFA21P	0n	29.99	28.85	kV	
PE.BFA9P	0n	29.02	28.16	kV	
POW	Status	CCV	AQN	Unit	
F16.DFA242	0n	14.79	14.91	kV	
F16.DFA254-ACT	0n				
F16.DFA254-S1		5.01	5.93	kV	
F16.DFA254-S2		5.09	5.93	kV	
F16.DFA254-S3		5.00	6.12	kV	
F16.DFA254-S4		10.46	11.37	kV	
F16.DFA254-S5		20.97	21.21	kV	
F16.DFA254-S6		20.37	19.58	kV	
STEP-V	Status	Move	AQN	Unit	
PE.SEH31ANO	At-Rest	65.000	65.090		
PE.SEH31CAT	At-Rest	88.000	88.230		
PE.SEH31HZAN	At-Rest	-0.600	-0.634		
PR.SMH16HZP0	At-Rest	55.500	55.470		
PR.SMH16HZAN	At-Rest	3.028	3.038		
GFAS	Enable	-	-	Unit	
	Enable	-	-		

Figure 14: Sheet with the PS extraction setting (CSOP console manager, WorkingSet window): the ERDs (DFA242 and DFA254) voltages are set here.

Step 3: preparing the SPS acquisition

Once the BPM delays in the **Batch Start Setting** box have been set or checked (if needed), see Fig. 11, the system is ready for the acquisition. Remember that YASP needs to be set into the **FTurn** mode. Four entries need to be specified, even if their default values shall not be changed:

- **Delay incr./step[microsec]**: is the time that is internally used to shift the **Sampling Delay** in order to move from one slice to the next and corresponds to the PS revolution time or, equivalently, to the slice length, $2.1 \mu\text{s}$.
- **No. steps**: corresponds to the number of slices (5).
- **No. of cycles to skip**: in the number of SPS cycles to skip after changing the above sampling delay. At least one cycle should be given to give the electronics enough time for being updated.
- **No. acquisition/step**: is the number of data sets acquired for each slice. This is done to have a minimum statistics and is set to 3 in the correction routine: additional acquisitions will not be analyzed. In case of a wrong acquisition because of the above mentioned synchronization issue, large discrepancies between the three sets will appear.

Before launching the acquisition, check that the sum signal displayed by YASP is above 1000. If not, the BPM gain should be increased.

Launch then the acquisition by clicking on the **SCAN!** button.

Notice that during the automatic acquisition, an **Error** message may show up in the main YASP dialog box (most right side of the window of Fig. 10), whenever the beam is not injected in the SPS:

```
Fit 2D failed: less than 2 valid BPMs
```

Since the corresponding data are not skipped, the entire acquisition has to be rejected and relaunched.

Step 4: preparing and launching the corrector routine

Once the SPS acquisition is over, the correction routine can be launched by clicking on the **Show Fit Panel** box. A new window will pop up (see Fig. 15) where the actual ERD setting (the one implemented during the previous SPS acquisition) needs to be defined before the correction script is run.

The actual ERD setting can be displayed from a **CPSOP** console manager, after opening the **WorkingSet** window, see Fig. 14. For a fast check of the DFA242

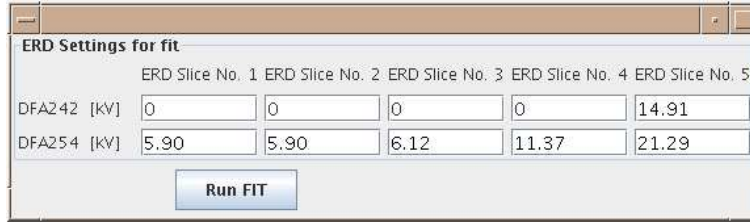


Figure 15: Snapshot of the correcting script dialog box, where the actual ERD setting needs to be defined before launching the script from the Run Fit! button.

start time, namely the turn in which it is powered, the fast-sampler signal (which sums the voltages of both kickers) can be displayed.

Once the actual ERD setting is typed, the correcting routine can be launched by clicking on the **Run Fit!** button. The script might take a few minutes.

Step 5: displaying the results and implementing the results

When the script exits, the ERD corrector setting will be displayed in the main YASP dialog box, see Fig 16. Notice that a new ERD setting might not be accepted if its voltage is lower than the one defined in other cycles, even in those not using the ERDs (LHC, AD, etc.). If this happen, the ERD settings of all cycles shall be edited and changed with (dummy) voltages lower than the new setting¹². A further global steering in TT10 might be performed by means of MICADO, as the ERDs may change the centroids of the five slices, that hence needs to be re-steered. See discussion of Sec. 4 and Fig. 7.

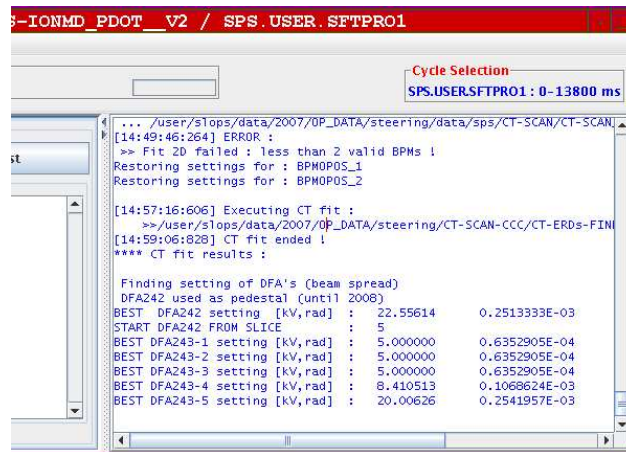


Figure 16: Snapshot (zoom) showing the final result of the corrector routine.

¹²The best solution is to set them to 5 kV, which is the lowest accepted value

Step 6: evaluate the correction goodness

In order to assess the correction goodness, a first look at the SPS injection losses should be given: lower oscillation should lead to lower losses.

For a more direct comparison, click on the **show results** button in the PS-CT-Check window of Fig. 11. A new window will pop up displaying the vertical oscillation amplitudes of the five slices during the first turn of injection, over the first two sextants (see Fig. 17). This plots represents the status before correction. After implementing the new corrector setting, another automatic acquisition should be launched as in **Step 3**. By displaying again the oscillation amplitudes you can evaluate how effective has been the correction: lower amplitudes indicate a good correction.

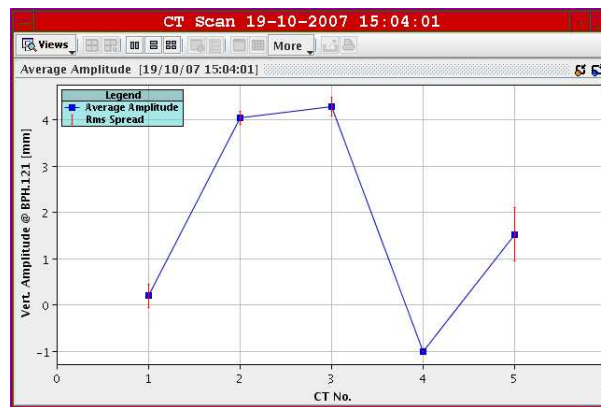


Figure 17: Snapshot of the **show results** window showing the vertical oscillation amplitudes of the five slices in the first two SPS sextants during the first turn. After correction lower values indicate an improved trajectory.

B APPENDIX: PS-CT-Check code structure

The corrector routine is composed by several modules called sequentially. All the modules and programs internally called have been compiled for running under Linux only. The main script CT-ERDs-FINDER performs the following actions:

- fetch the SPS trajectory data previously acquired by YASP;
- read the actual ERD setting given in input by the user and include it in the MAD-X files used for tracking;
- convert the SPS data in a format suitable both for MAD-X and for plotting the first SPS sector only;

- launch a MAD-X script for inferring the horizontal five initial conditions at the beginning of TT2, \vec{P}_i ;
- an independent routine is called from the MAD-X script in order to compute the best ERD corrector setting;
- MAD-X is run again with the new setting for simulating the correction;
- put all the output files (measured trajectories, initial conditions, best corrector setting and simulated vertical trajectories in the SPS) in the OUTPUT directory;
- display the best ERD corrector setting.

The main script has been installed in the following directory

```
/user/slops/data/2007/OP_DATA/steering/CT-SCAN-CCC
```

togheter with the FORT directory containing all the external routines called in the MAD-X script, the INPUT directory where the initial SPS file are stored and manipulated, the MADX directory where all the MAD-X files and scripts are stored, and the OUTPUT directory. At the end of the run, the best ERD corrector setting is copied in the `erds_correction_setting.txt` file, the one then displayed by YASP.

References

- [1] R. Cappi and M. Giovannozzi, *Computation of betatron mismatch and emittance blow-up for Multi-Turn Extraction*, CERN/PS 2002-083 (AE).
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- [4] B. Autin and Y. Marti, *Closed Orbit Correction of Alternating Gradient Machines using a small Number of Magnets*, CERN/ISR-MA/73-17 (1973).
- [5] F. Schmidt, *MAD-X Users Guide*, Version 2.12, CERN, (2003), <http://mad.web.cern.ch/mad/>.
- [6] LabView is a National Instrument's product, <http://www.ni.com/labview/>.