OPTIMIZATION OF THE POSITION OF THE RADIAL LOOP PICKUPS IN THE CERN PS

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Abstract

A part of the beam losses at transition crossing of high intensity beams in the CERN PS have been attributed to an excursion of the closed orbit. The orbit jump occurs simultaneously with the jump of the transition energy triggered by pulsed quadrupoles. Investigations showed that the position of the pickups used for the radial loop system was not optimized with respect to the dispersion change caused by the fast change of the transition energy. Thanks to new electronics of the orbit measurement system, turn-by-turn orbit data could be recorded around transition crossing. Their analysis, together with calculations of the transverse optics, allowed determining a new choice of pickup positions for the radial loop. In comparison to the previous pickup configuration, the new configuration improves the mean radial position not only during transition crossing, but all along the acceleration cycle.

INTRODUCTION

It is well known that one of the bottlenecks limiting the performance of the CERN Proton Synchrotron (PS) is the acceleration of high intensity beams through the transition energy γ_{tr}. To minimize the duration during which the beam energy stays close to γ_{tr}, a so-called γ_{tr} jump is applied [1]. Some 50 ms before the transition jump, γ_{tr} is slowly pushed higher in energy. To cross the transition energy as quickly as possible, fast pulsed quadrupoles are triggered to rapidly change γ_{tr}. Measurements of the horizontal orbit on a single bunch beam with $1.3 \cdot 10^{13}$ protons show a mean radial position (MRP) excursion of about 3.5 mm at the same time as the γ_{tr} jump, provoking significant beam losses. The radial position is controlled by the radial loop system which originally used the horizontal beam position averaged over three dedicated pick-ups (PUs). With the help of orbit measurements, this study presents how an improved set of radial PUs has been identified to control the MRP. The method consists of analyzing the dispersion bump caused by the γ_{tr} jump to find the best location of the PUs to be more sensitive to energy errors and reduce losses at transition crossing.

MEAN RADIAL POSITION AT TRANSITION CROSSING

Transition crossing in the CERN PS is carried out by a second order γ_{tr} jump performed by quadrupoles arranged in doublets and triplets. Losses have been measured for high intensity beams during the γ_{tr} jump. A fraction of these losses are related to the large beam envelope due to the optics distortion of the γ_{tr} jump. However horizontal orbit measurements at transition crossing also showed a MRP excursion when the γ_{tr} jump is performed. An example of measured MRP from a beam with a 1 σ horizontal physical emittance of 9 mm.rad and an intensity of $1.3 \cdot 10^{13}$ ppp is presented in Fig. 1. The radial position deviates by 3.5 mm at the γ_{tr} jump due to the inversion of the currents in the doublets [3]. Of that excursion, 1 mm has been attributed to the misalignments of the quadrupoles used to perform the γ_{tr} jump. An artificial radial steering was thus introduced to compensate this deviation, which appears to be a good temporary solution to reduce the losses. Further tests have been carried out to optimize the radial loop system controlling the radial position of the beam in order to automatically compensate the MRP drift.

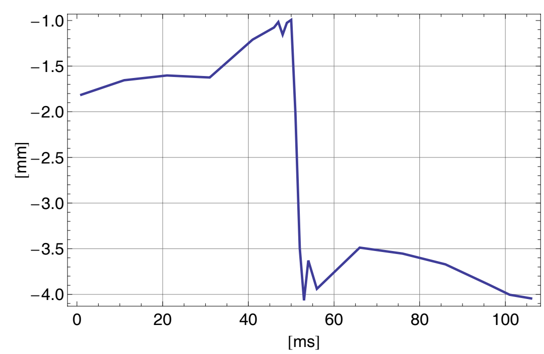

Figure 1: MRP in mm as a function of time during the transition crossing with the γ_{tr} jump scheme. The transition time is situated at 50 ms.

CLOSED LOOP CONTROL OF RADIAL POSITION

During large parts of the acceleration, an RF frequency calculated from the measured field in the bending magnets would be sufficient to keep the beam close to the center of the beam pipe. However, according to $\Delta R/R = (\gamma_{\mathrm{tr}}^2/\gamma^2 - 1)^{-1}\Delta f/f$, the offset of the radial position ΔR becomes significant for $\gamma \simeq \gamma_{\mathrm{tr}}$ in case of small errors Δf of the calculated frequency program. A radial loop therefore introduces a correction to the frequency program based on a measurement of the radial position offset of the beam. In the 1970s, four radial loop PUs had been installed in straight sections (SS) 22, 36, 51, 96, out of which the PU in SS36 had not been in use [5]. Each of the PUs delivers sum (Σ) and difference (Δ) signals. The pairs of Σ and Δ signals are then converted to an intermediate frequency ($f_{\mathrm{IF}} = 21.4\,\mathrm{MHz}$), selecting only the spectral component of the beam at the RF frequency. The Δ/Σ division is performed by a time normalizer circuit [6], resulting in a radial offset per PU being largely independent from beam intensity and bunch length. The radial offsets measured at the different PUs are then averaged and injected, via an appropriate loop filter, as slow corrections to the RF frequency sent to the accelerating cavities. At transition crossing, i.e. when $(\gamma_{\mathrm{tr}}^2/\gamma^2 - 1)$ changes sign, the gain of the radial loop is inverted, which may introduce a transient. The stable phase program is switched from ϕ_s to $-\phi_s$ in addition. Ideally, this should only move the reference phase of the beam phase loop. Since its differentiated form acts like a radial steering, any error in the stable program at transition crossing translates to a radial perturbation.

DISPERSION FUNCTION AT THE RADIAL PUS

The average of the dispersion function has been computed with MADX [4] during the γ_{tr} jump and compared with the one at the location of each radial loop PUs. The results are shown in the Fig. 2 and Fig. 3. The PU in SS51 is less sensitive to energy errors due to a lower dispersion during the γ_{tr} jump compared to the two other PUs in SS22 and SS96 used in the old configuration for the radial loop (PU36 shown for completeness). This is confirmed by observing the trajectories turn-by-turn through transition at the PUs locations (Fig. 4). The change in trajectory at the PU51 is small with respect to the other PUs. In addition the phase advance between the PUs in SS51 and SS96 is not suitable since it is not close to $\pi/2$. To replace the PU in SS51, the fourth radial loop pick-up in SS36 has been put back into operation. Additionally, a new pick-up has been installed in SS76 during the shutdown 2008/2009 (in total five dedicated PUs in SS22, 36, 51, 76, 96). SS76 is more appropriate considering the change in horizontal position through transition (Fig. 4) and the betatron phase advance with respect to the other radial loop PUs. The dispersion function in SS76 from the Fig. 5 shows that its sensitivity to energy errors is increasing during the γ_{tr} jump. The resulting dispersion of several PU combinations is also presented in the Fig 5. The set of PUs in SS22, 36, 76, 96 is therefore the best choice to maximize the radial loop sensitivity to energy errors.

MRP MEASUREMENTS WITH A NEW SET OF RADIAL PUS

Comparative MRP measurements have been performed for three PU configurations: first with the old set of radial PUs (SS 22, 51, 96), in the second case a radial steering was added, and the third case was done with the new set of PUs (SS 22, 36, 76, 96) in the absence of any radial steering. The measurements were done exclusively with high intensity beams. The MRP is then calculated from the

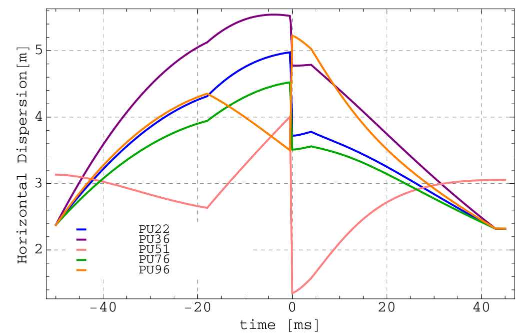

Figure 2: Calculated dispersion functions seen by the PUs from the radial loop system during the γ_{tr} jump versus time. The γ_{tr} jump occurs at 0 ms.

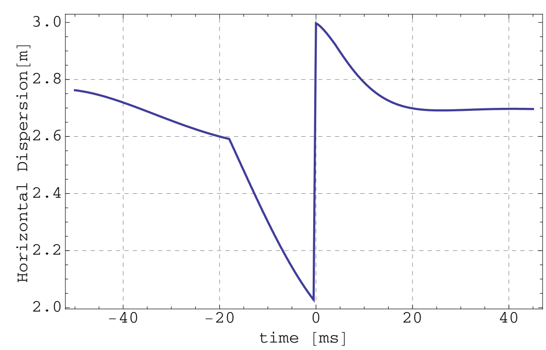

Figure 3: Average dispersion function of the PS machine during the γ_{tr} jump as a function of the time.

40 Beam Position Monitors (BPMs) used to determine the closed orbit. The results are presented in the Fig. 6 and Fig. 7 for the beams named CNGS ($2.5 \cdot 10^{13}$ protons in 16 bunches accelerated through transition on $h = 16$) and ToF (single bunch accelerated on $h = 8$ with $7.5 \cdot 10^{12}$ ppp) with respectively a 1 σ normalized horizontal emittance of 5 mm.mrad and 12 mm.mrad. The transition time are respectively 317 ms for the ToF beam and 560 ms for CNGS with respect to the start of the cycle. With the new configuration the beam stays well centered in the machine even

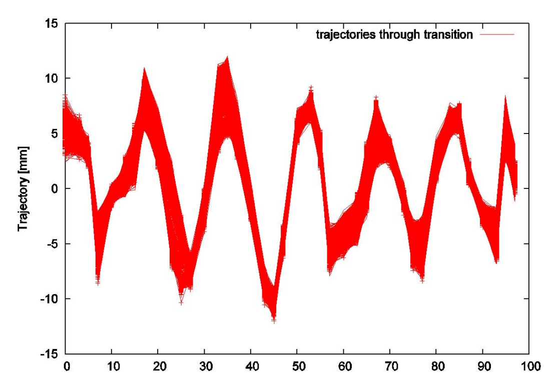

Figure 4: Horizontal beam position offset along the circumference measured around transition.

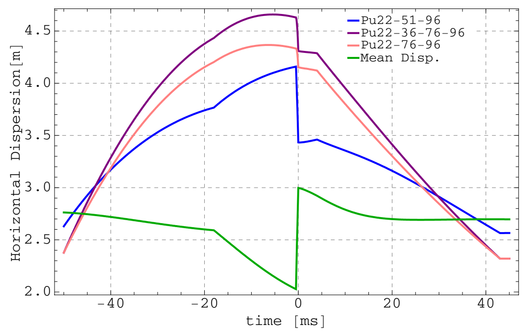

Figure 5: Dispersion functions seen by different PUs combinations of the radial loop system versus time during the γ_{tr} jump.

outside the transition region due to the improved betatron phase advance between the radial PUs. The MRP during the γ_{tr} jump is not affected as much as before since the system is more sensitive to dispersion change. Concerning the losses, as expected a large reduction of beam losses is observed. However the amount of losses is equivalent to the level with a radial steering as shown Fig. 8, as an example, the losses at a BLM situated in SS63. This section is usually a hot spot for irradiation at transition crossing.

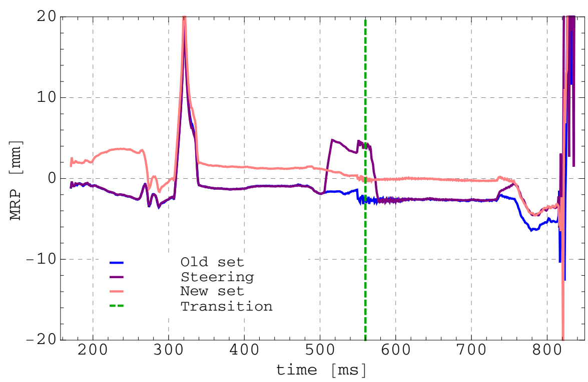

Figure 6: MRP along the CNGS cycle in three cases: with the old set of PUs and without radial steering, with the old set of PUs and with radial steering, with the new set of PUs and no radial steering. Transition time is crossed at 560 ms.

CONCLUSIONS

The new set of PUs is an improvement for the efficiency of the radial loop PUs system according to the optics change during the γ_{tr} jump. This allows a better steering of the beam all along the magnetic cycle without many additional steering, making the operation of the beam easier.

AKNOWLEDGEMENTS

The authors would like to express their gratitude to J. Belleman, S. Hancock, G. Metral, M. Schokker, G. Arduini, H. Genoud, M. Delrieux, R. Steerenberg, R. Bruce

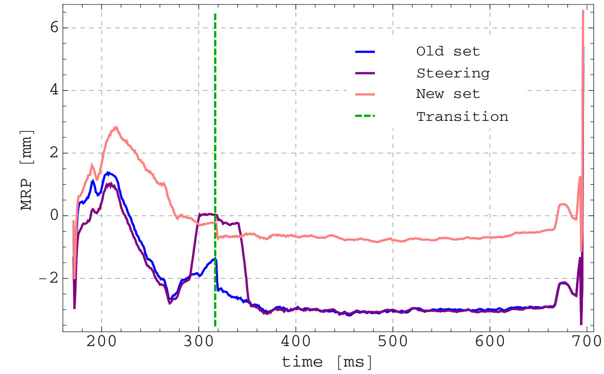

Figure 7: MRP along the ToF cycle in the same three cases as in Fig.6. Transition time is crossed at 317 ms.

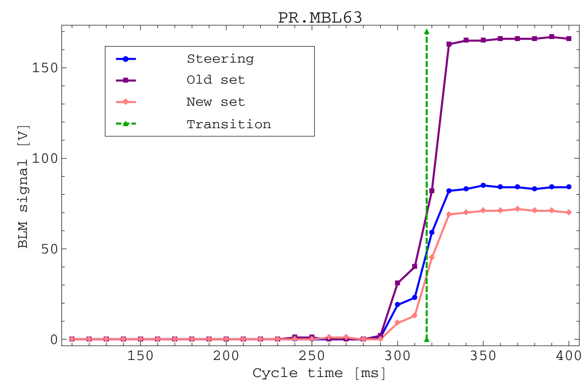

Figure 8: Integrated radiation dose for the ToF beam at the BLM in SS63 during the γ_{tr} jump. The blue curve represents the losses with the radial steering, the purple one with the old set of PUs and the green one is with the new set.

and the PS Operation for their collaboration during the MDs.

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