DESIGN AND BEAM MEASUREMENTS OF MODIFIED FAST EXTRACTION SCHEMES IN THE CERN PS FOR INSTALLING A DUMMY SEPTUM TO MITIGATE RING IRRADIATION

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Abstract

The proposed Multi-Turn Extraction (MTE) for the CERN PS allows reducing the overall extraction losses for high intensity beams. The required longitudinal structure of the proton beam induces unavoidable beam losses at the magnetic extraction septum. The installation of a dummy septum with an appropriate shielding has been proposed to localize losses and to shadow the magnetic septum. Such a device, located in the extraction region, imposes tight constraints on the available beam aperture. Modified extraction schemes have been proposed, which will be presented and discussed in detail in this paper together with the measured performance.

INTRODUCTION

The proposed MTE is based on transverse splitting by means of resonance crossing [1]. During the MTE beam commissioning it was observed that the extraction process led to an increase in the activation of the extraction septum in straight section (SS) 16 of the PS ring. Different solutions have been studied [2] and the installation of a dummy septum in SS15 has been proposed to move the losses from the magnetic septum to a well-shielded location [3, 4]. The installation of the dummy septum is essential for the future extraction of high intensity beams; its compatibility with the operation of the machine for the other beams had to be assessed. For these beams the dummy septum represents a challenging aperture restriction. The horizontal beta function is larger in SS15 than in SS16 by a factor 1.8 and therefore the displacement of the kicked extraction trajectory and the beam sizes are larger in SS15 making the aperture reduction a critical constraint.

NEW EXTRACTION SCHEMES

New extraction schemes were designed aiming at reducing the horizontal displacement in SS15 while providing a clean extraction process. Constraints were also imposed in terms of extraction losses and extraction conditions (horizontal position/angle) for the LHC type beams. The new schemes exploit all the existing hardware. Figure 1 displays the elements used for the fast extractions. The unmodified scheme is the same for all beams and consists of the classical combination of a slow quasi-closed bump (generated by 4 bumper magnets located in SS12, 14, 20 and 22 powered with the same currents) and a fast kicker, located in SS71/79†. The new schemes differ from the original one by two key ingredients: they exploit the independent powering of the 4 bumpers and they use 3 additional kickers located in SS4, 21 and 13 and originally installed only for MTE [1]. Unbalancing the kicks of the bumpers 12/20 and 14/22 allows to increase the angle of the closed bump in SS15 while maintaining a constant position in SS16. New slow closed bumps have thus been implemented for each scheme with the advantage of a better bump closure. Using additional fast kickers allows to benefit from the phase advance relationships between these kickers and SS15 and 16 (see Table 1).

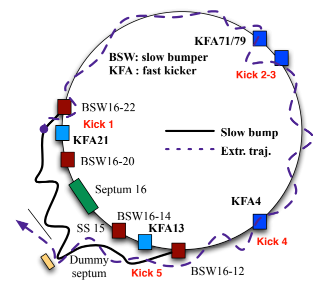

Figure 1: PS extraction elements and schematics of the new TOF extraction scheme.

Table 1: Horizontal Phase Advance Relationships

	KFA21	KFA71	KFA4	KFA13
SS15/16	313°/331°	270°/293°	248°/271°	45°/68°

One can see that a positive kick with KFA71 leads to a larger displacement in SS15 than in SS16. On the other hand KFA13 and KFA4 will have their kick translated into a larger displacement in SS16 than in SS15. Therefore reducing the kick from KFA71 and using additional kicks from KFA4/13 will help reducing the displacement in SS15 while keeping it constant in SS16. KFA71 is still needed, as the two other kickers do not have enough strength. The use of KFA21 follows the same idea, although, as its polarity is inverted it will actually reduce the excursion in both sections, more in SS15 than in SS16. The new schemes thus use KFA21 in combination with an increase in the kicks of the other 3 kickers.

The installation of the dummy septum imposes the removal of a dipole magnet used for high-energy orbit correction. An extensive simulation campaign has been

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† Kicker 71/79 consists of two groups of magnets. The phase advance between them is 180° and they can be considered as a single kicker.

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performed and a new set of orbit correctors was installed. It consists of three dipoles in SS5, 18 and 60. The implementation of the new extraction scheme has been tested with that orbit correction in place.

MEASUREMENTS RESULTS

LHC Type Beams

The variants of the LHC type beams (various longitudinal structures, transverse emittances and intensities) are accelerated to 26 GeV/c and fast extracted. The impact of stray fields at PS extraction on beam quality is non-negligible. We imposed the new extraction scheme for LHC to recover the same extraction conditions as the old one. At 26 GeV/c the closed orbit is corrected using dedicated dipole magnets. The new orbit correctors proved to be very effective. The RMS closed orbit is reduced by a factor 2, performing better than the old one (Fig. 2).

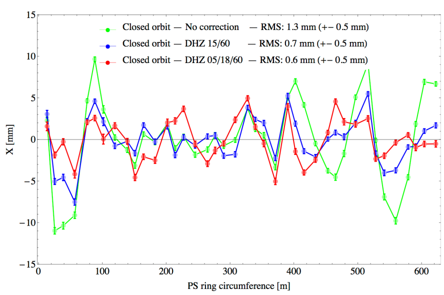

Figure 2: Measured closed orbit at 26 GeV/c for LHC beams.

The new scheme uses 4 bumper magnets with independent current and keep the usual kicker KFA71 for the fast extraction. Figure 3 shows the closed extraction bumps with the closed orbit subtracted. The two bumps have different positions in SS15 and SS17 but the same position and angle in SS16. The new bump also features a closure 60 $\pm$ 13 % better. The results show a slight increase of the transverse position of the extraction trajectory in SS15, from 71.4$\pm$0.7mm to 72$\pm$1mm.

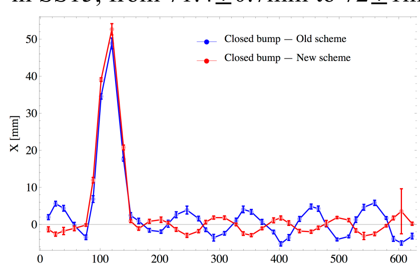

Figure 3: New and old extraction bumps for the LHC beams at 26 GeV/c.

The beam has been successfully injected in the SPS and scraping measurements were performed to assess the transverse beam quality. The measurements did not reveal significant differences between the two beams and it was concluded that the new scheme does not induce emittance growth or tails, as depicted in Fig. 4, where the comparison between scraping measurements done for the old and new schemes in the SPS is shown. Similar results have been obtained for the LHC Pb^{54+} ion beam. Additionally a first version of the new scheme has been used for the physics fills 3377 and 3378 of the LHC. The bump was not fully optimized in terms of the horizontal position of the trajectory in SS15 but the same procedure was applied to recover the same extraction conditions as for the old scheme. The new bump was transparent to the performance of the LHC beam.

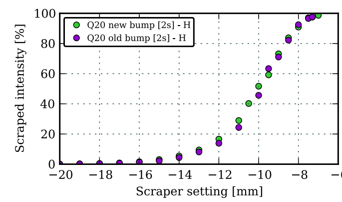

Figure 4: Scraping measurement in the SPS.

n-TOF Beams

The beam sent to the n-TOF experiment is a single high intensity (around 750×10^{10}p) bunch undergoing a bunch rotation a few milliseconds prior to extraction. Two main issues complicate the extraction of that beam: a large transverse emittance and a large $\Delta p/p$ value (induced by the bunch rotation) which, due to the non zero dispersion in the extraction region, also leads to a larger beam size. In addition the TOF beam exists also in the form of a so-called parasitic beam: a two-bunch beam is accelerated to 20 GeV/c, one bunch is extracted while the other one is kept in the machine and further accelerated to 24 GeV/c. The intensity of the parasitic TOF bunch is limited to 400×10^{10}p, implying a smaller size. The new hardware was used for the orbit correction at 20 GeV/c (nominal beam) and led to a reduction of the RMS orbit distortion of 20%. Secondly a new closed bump was obtained, allowing a reduction of the closed bump in SS15 by 10$\pm$1mm. A reduction of the horizontal position of the extraction trajectory was first obtained with the additional kickers KFA4 and KFA13 but it was soon realized that this was not enough to overcome completely the aperture restriction. A final scheme using the kickers 71, 4, 13 and 21 was designed. It is depicted in Fig. 1. On top of the slow closed bump the bunch is kicked 5 times by the different kickers. The strength of these kicks is compatible with the aperture in the rest of the machine and it leads to a drastic improvement of the situation in SS15, as shown in Table 2. The situation for the parasitic TOF beam is more complex. Indeed, the kickers KFA13-21 generate a pulse corresponding to 5 machine turns thus also kicking the non-extracted bunch for 5 turns. It is possible to obtain a fast closed bump between SS13 and 21. In the new scheme, the parasitic TOF bunch experiences the same extraction trajectory as the nominal TOF bunch, while the other bunch sees a fast closed bump only. We successfully assessed that the additional manipulation of the second bunch does not induce any emittance growth. The results are summarized in Table 2.

Table 2: Improvements in SS15 of the New TOF Schemes

	KFA 71	KFA 71, 04, 13	KFA 71, 04, 13, 21
Nominal	90.3±0.7 mm	73.2±0.8 mm	65.1±0.9 mm
Parasitic	70.6±0.4 mm	-	64.7±0.1 mm

The new schemes for the TOF beams allow to overcome the aperture restriction with a gain in horizontal displacement of the extraction trajectory for the nominal beam (parasitic) of 25±1mm (5.9±0.4 mm).

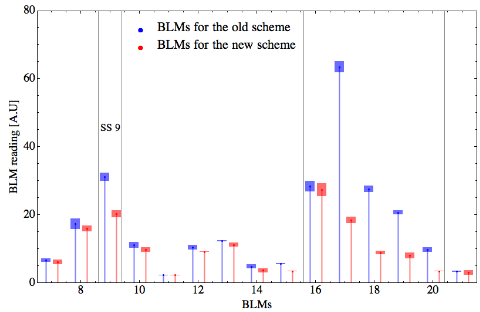

Figure 5: BLMs readings for the nominal TOF beam.

The new extraction scheme also allowed a reduction of the beam losses at extraction as measured by the Beam Loss Monitors (BLMs). In the ring, we observed a reduction of a factor 1.5 in SS9, which is one of the less shielded sections of the machine, and a reduction in four sections downstream of the extraction septum, indicating a cleaner extraction. No significant difference could be found in the other parts of the ring. The losses at the beginning of the transfer line could also be optimized. The new extraction scheme was successfully used in operation for physics from the Dec. 12 until Dec. 16 of the 2012 run.

AD Beam

The AD beam consists of 4 bunches of total intensity around 1500×10^{10}p extracted at 26 GeV/*c*. A bunch rotation is performed, leading to an increased transverse beam size at extraction. The original extraction scheme is not compatible with the aperture restriction of the dummy septum. Results with beam showed that the optimum scheme comprises the kickers KFA71, KFA13 and KFA21. A new closed orbit correction and slow closed bumps have been put in place, prior to the setting up of the extraction kickers. The results show a reduction of the transverse position of the extraction trajectory in SS15 of 11.5±1.5mm, for a position of the new scheme of 68.7±0.7mm. The beam with the new settings was successfully sent to the target for antiprotons production on Dec. 15 and 16 during the 2012 run.

Dummy Septum Aperture in SS15

The horizontal position of the dummy septum blade is imposed by the optics between SS15 and 16. The maximum shadowing efficiency has been found for a blade located at 85.3±0.5 mm. The dummy septum aperture is shown in Fig. 6 with the extraction beam envelopes, including the extracted MTE islands. The extraction trajectories are compatible with the position of the blade. The beam sizes assume Gaussian distributions and assume 3 betatron versus 2 synchrotron standard deviations. Table 3 displays the beam sizes along with the distance between the edge of the envelope and the blade for the different beams. The latter is a measure of the available aperture margin.

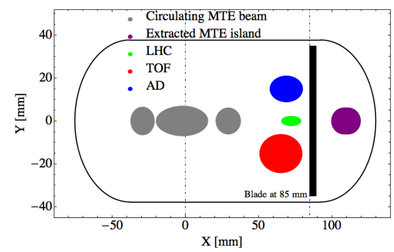

Figure 6: Dummy septum aperture and beam envelopes.

Vertical positions of the AD and TOF beams are artificially shifted by ±15mm for clarity.

Table 3: Horizontal Sizes and Distances from the Blade

	LHC	TOF (nom.)	AD
Beam radius [mm]	6.8±0.3	14.7±0.6	11.4±0.3
Distance [mm]	8±1	20±1	16.6±0.9

CONCLUSION

New extraction schemes have been implemented and benchmarked at the CERN PS. They optimize the trajectories of the fast extracted beam and are compatible with the aperture restriction imposed by the dummy septum. These schemes have been successfully put in physics operation for AD and TOF and the new LHC beam has been sent to the SPS without emittance growth.

ACKNOWLEDGMENT

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