# MODIFIED EXTRACTION SCHEME FOR THE CERN PS MULTI-TURN EXTRACTION

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*Abstract*

High-activation of the extraction magnetic septum of the CERN PS machine was observed due to the losses of the continuous beam extracted via the Multi-Turn Extraction (MTE) method. A possible mitigation measure consists of using an existing electrostatic septum, located upstream of the extraction magnetic septum, to deflect the beam. This would highly decrease the beam losses, and hence the induced activation, during the rise time of the MTE kickers due to the reduced thickness of the electrostatic septum with respect to the magnetic one. The layout of this new extraction will be described in detail and the results of beam measurements presented.

## INTRODUCTION

The PS Multi-turn extraction (MTE) [1] was proposed to mitigate the extraction losses due to the shaving process that is at the heart of the Continuous Transfer (CT) mechanism proposed in the seventies to transfer a beam from the PS to the SPS [2, 3]. The implementation, described in details in [1], was completed in 2008 when the hardware commissioning and the first beam commissioning started [4]. In 2010 the PS and SPS start-up were planned to be performed only with the MTE beams and the CT kept as fall back solution. Reasonable intensities, in excess of $2\times10^{13}$ p/PS batch, were achieved. However, in May 2010 a too large activation of the magnetic extraction septum 16 was measured and the decision to revert to CT was taken. This was based on the need to minimise the time required for an intervention in the septum area in case of a failure after several months of operations. The increased activation of the septum was not considered to have an impact on the reliability of the device, but only on the cool down time required to access the area in case of an intervention. Furthermore, such an increased cool down time would have had a negative impact on the LHC physics run in case of break down in the PS in the extraction region.

The losses on the septum causing the activation are due to the longitudinal structure of the beam (completely de-bunched) and the long rise time of the kickers compared to the revolution period. In the MTE Design Report [1] two strategies were considered and proposed to reduce the impact of the kicker rise time: firstly, a bunched version of the beam (either using h=8, or h=16 in the PS); secondly, a thinner magnetic septum. The efficiency of the first option could not be evaluated on paper and only beam tests by injecting the beam in the SPS could provide the final answer. The bunched version of the MTE beam had to be discarded due to a degradation of the SPS transmission efficiency. The latter option was considered to be too expensive for the actual benefit that it could bring and therefore it was not retained. Parenthetically, radioprotection measurements have clearly shown that the rest of the PS ring benefited from the MTE as global beam losses were much reduced with respect to the corresponding situation with CT, except, unfortunately, in the extraction septum region.

Intense efforts were devoted to performing systematic measurement campaigns as well as paper studies to find mitigation measures to the observed phenomena that were (and still are) limiting the MTE performance. These are: beam losses on the magnetic septum due to the beam lost during the rise time of the kickers; fluctuations in the fraction of beam trapped in the islands; fluctuations in the injection trajectories in the SPS.

A number of mitigation measures have been proposed, like the installation of a dummy septum [5] or a hybrid MTE extraction scheme that is the subject of this paper.

By hybrid MTE scheme, we mean a new manipulation in which the extraction of the split beam is performed using also the electrostatic septum that is used for the CT scheme plus, eventually, some of the CT kickers. While for the CT the electrostatic septum is used to deflect particles as well as to shave the beam over the five extracted turns, in the case of the MTE only its first function will be used, as the beam will be split transversally by the resonance crossing. The hybrid scheme should be compatible with the CT operation during the transition phase, thus requiring to keep in operation some CT hardware that was originally assumed to be de-commissioned with the advent of MTE. Furthermore, the constraint of having always available the CT imposes not to alter the layout of the CT extraction elements, which, in turns, implies applying all the optics manipulations that are performed during the CT extraction also to MTE.

In principle, either dummy septum or hybrid MTE would be enough for mitigating the activation of the magnetic septum. Nevertheless, we think it is worth to pursue both approaches in parallel and even to have them both in operation to provide the best suppression of losses in the PS ring.

Other mitigation measures have been considered. For instance, the possibility of creating a gap in the longitudinal beam structure has been considered, but, it has been discarded because of performance considerations for either the SPS machine, or the experiments using the SPS beam. Indeed, the gap in the beam structure would have been repeated four times in the SPS after injection and it would require increasing the peak beam current to maintain the total number of protons with an expected reduction of the transmission efficiency. The higher peak beam current would imply an increase of the slow extraction spill length to maintain the event pile-up rate at acceptable levels for the fixed-target Experiments.

Of course, the obvious solution of reducing the rise time of the extraction kickers has been considered and looked in details. It turned out that the beneficial impact on extraction losses was rather limited (only 80 % reduction of losses for a 100 % reduction of the rise time) and this had to be compared against a rather high implementation costs and an increased complexity of the whole system. Therefore, this option has been dropped.

## CONTINUOUS TRANSFER

The principle of the CT is based on few key elements: i) an electrostatic septum (located in straight section – SS – 31) is used to shave the beam and to deflect the fraction to be extracted; ii) a magnetic septum in SS16 is used to deflect the beam out of the ring; iii) two slow bumps are used to push the beam towards the two septa. The bump related with the electrostatic septum is generated by two dipoles in series; hence it is not perfectly closed; iv) a fast bump generated by kickers in SS21 and SS09, hence covering most of the PS circumference, is used to push the beam across the foil of the electrostatic septum during the extraction process proper. Such a fast bump is modulated on a turn-by-turn basis to provide the correct beam shaving. A sketch of the CT mechanism with the key elements is shown in Fig. 1 (from Ref. [6]). It should be recalled that the very principle requires having the fractional part of the horizontal tune set to 0.25.

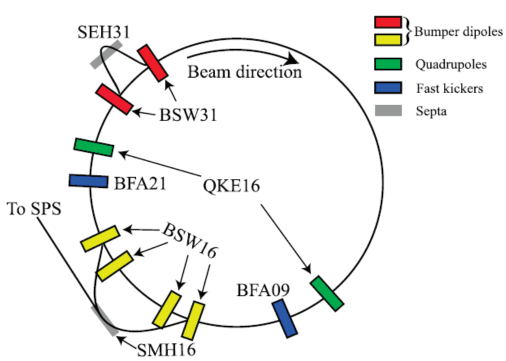


Figure 1: Sketch of the CT scheme.

The last ingredient is a set of special quadrupoles, the so-called kick enhancement – QKE, that have the function of changing the machine optics to adapt it to the need of the extraction (see Fig. 2 for details), as well as provide additional deflection to the extracted beam. Both the slow bumps and the QKEs have a rise time around 6-7 ms and during such a transient, the fractional part of the machine tune changes by 1-1.5×$10^{-2}$.

## PROPOSED MTE HYBRID SCHEME

The hybrid MTE scheme would be using the extraction elements of the CT, with the electrostatic septum being used only to deflect the beam. In fact, the beam shaving (of the CT) would be replaced by the transverse splitting (of the MTE). This, clearly, has the advantage of reducing the irradiation between the pure MTE and the hybrid one for the same longitudinal beam structure. In fact, while for the MTE the de-bunched beam should hit the magnetic septum blade (3 mm thick), in the hybrid version the beam would interact with the electrostatic septum foil (about 0.2 mm thick).

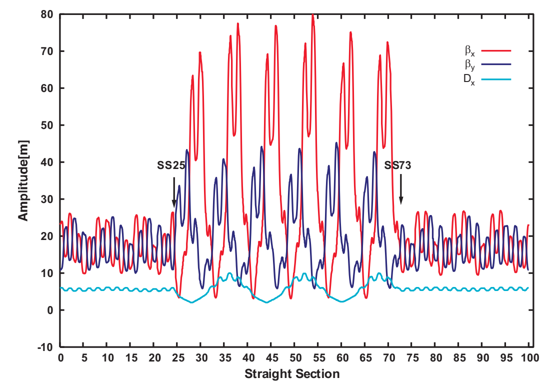


Figure 2: Optical parameters for the PS when the beam is sliced for CT. The standard optics is perturbed by special quadrupoles, the so-called QKE (indicated by the arrows).

To ensure an optimal performance of the hybrid MTE, the two slow bumps should be combined into one single super-bump in order to provide a closed structure over most of the machine circumference, with a great benefit in terms of aperture requirements (see Fig. 3 for an example of the super-bump). The constraint to have simultaneously the CT and the MTE in operational status imposes not to change the layout of the CT elements. In turn, this implies that the QKEs should have the appropriate phase advance with respect to the key elements and the correct kick enhancement effect. This is a tight constraint as the MTE is critically dependent on the tune value and a correction of the tune variation should be implemented. The other crucial point is to provide stable extraction conditions (position and angle) on a turn-by-turn basis.

The special beam structure (transversally split beam) and the PS lattice (combined function main dipoles) implies that a closed bump for one island is not necessarily closed for another one, as each island will see different feed-down effects from the non-linear components of the main magnet fields and of the non-linear extraction elements. This effect has been considered and a turn-by-turn change of the kickers' strength is mandatory, but a quantitative analysis is in progress.

The extraction of the fifth turn might also pose problems and should be looked at in details.




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## SOME MEASUREMENT RESULTS

On the experimental side, the first aspect considered has been the closure of the super-bump, which has been successfully achieved.

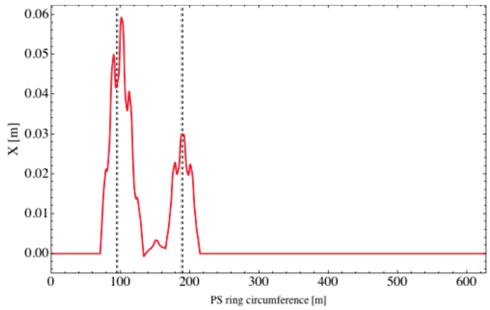


Figure 3: Form of the super-bump used to push the MTE beam to the electrostatic (SS31, lower-amplitude bump) and magnetic (SS16, higher-amplitude bump) septa. The perfect closure is clearly visible.

The second delicate point, namely the tune variation during the rise time of the slow bump and QKEs, has been tackled starting from the measurement of the tune during the 6-7 ms. On such a short time-scale the standard tune measurement system, based on beam excitation via a chirp signal, is not adapted. In fact, the beam is excited over a period of 2 ms, thus allowing only for two or three meaningful measurements during the rise time process. Therefore, the extraction kicker was used to excite the beam and the tune has been extracted by analysing the turn-by-turn pick-up data (see also Ref. [7]). The outcome of the measurements and their analysis is shown in Fig. 4. The maximum difference between measurement and model is of the order of $5\times10^{-3}$.

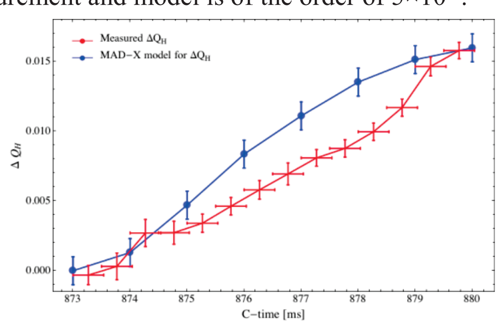


Figure 4: Measured and predicted horizontal tune vs. time during the rise time of the super-bump and QKEs.

The vertical tune cannot be measured in this way, but the model can be used, after a possible re-calibration based on the comparison with the measurements in the horizontal plane. In Fig. 5, an example of the effect of the fast tune change is shown. A single bunch is kicked inside the island and, due to the fast, non-adiabatic, tune variation the beam filaments (left), while when a partial compensation of the dynamic effect is applied, then a smaller filamentation is obtained, and a coherent signal lasting longer is visible (right). However, the target would be to have a long-lasting coherent signal, which is still not achieved.

## CONCLUSIONS AND OUTLOOK

A hybrid extraction layout for the MTE aimed at mitigating the irradiation of the magnetic septum 16 has been proposed. Detailed checks are planned to improve the performance, on paper, of the scheme. Specifically, the fast bump should be better closed over the five extracted turns in order to provide constant extraction conditions.

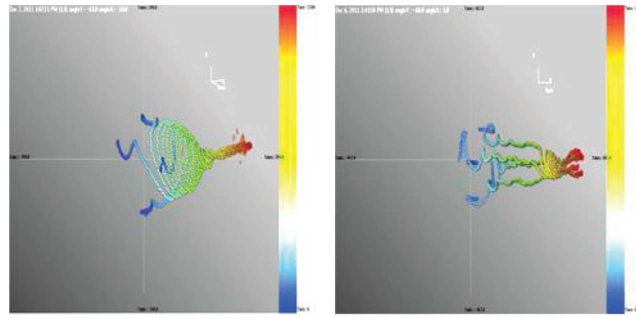

Figure 5: Pseudo phase space reconstruction obtained by kicking a single bunch beam into the stable islands without correction of the tune variation (left) and with partial correction (right). The colour code represents the time evolution (from blue to red). The two plots have the same scale.

The other crucial point is the tune variation during the rise time of the slow bump and the QKE quadrupoles. The transverse splitting relies on a well-defined and constant tune value. The fast tune variation goes against this principle, but it can be easily compensated unless in reality hardware limitations are found. Detailed measurements have been performed and presented in this paper. The next step will be to implement appropriate tune compensation and to assess its performance.

## ACKNOWLEDGMENT

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