NUMERICAL SIMULATIONS TO EVALUATE THE PERFORMANCE OF CERN PS DUMMY SEPTUM TO REDUCE IRRADIATION FOR THE MULTI-TURN EXTRACTION

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Abstract

The losses created by the proposed Multi-Turn Extraction (MTE) at the CERN PS induce high activation of the magnetic extraction septum due to the de-bunched longitudinal beam structure requested to transfer the beam to the SPS. A mitigation measure is under study aiming at localizing the losses in a well-shielded area by shadowing the magnetic extraction septum thanks to a septum-like passive device. Such a solution is based on a so-called dummy septum, a blade which absorbs particles during the rise time of the extraction kickers for MTE beams. The efficiency of the scheme is presented in this paper. The quantitative estimate is based on detailed simulations that analyze the beam-matter interaction and provide a determination of the shadowing effect of the dummy septum.

INTRODUCTION

The Multi-Turn Extraction (MTE) is the proposed method to replace the Continuous Transfer (CT) extraction for high intensity beams at the CERN PS [1]. It is based on transverse splitting by means of beam trapping into stable islands. That manipulation is to a large extent independent on the longitudinal beam structure and, as required by the SPS, de-bunched beams are extracted. It was soon realized that the extraction induced too large losses on the magnetic extraction septum: during the rise time of the kickers (10-90% in 350 ns), the de-bunched beam interacts with the blade of the magnetic septum [2]. Several mitigation measures were studied before [3], the efficiency of the dummy septum scheme is studied and reported upon in this paper. The device, described in detail in Ref. [4], consists of a passive septum-like blade whose function is to shadow the blade of the extraction septum from the beam losses. It is located in Straight Section (SS) 15, upstream of the magnetic septum (SS16), a region where additional shielding can be installed.

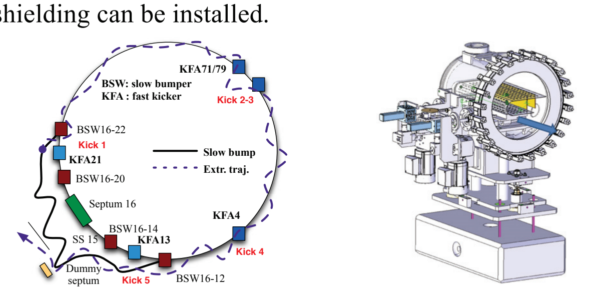

Figure 1: PS extraction elements (right) and 3D model of the dummy septum (right).

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Figure 1 displays a 3D model of the dummy septum with its vacuum tank. The complete geometry of the PS tunnel is modeled in FLUKA [5]. The dummy septum geometry has been added, along with the concrete shielding surrounding the assembly. A view of the FLUKA geometry of the PS extraction region comprising the dummy septum shielding is shown Fig. 2.

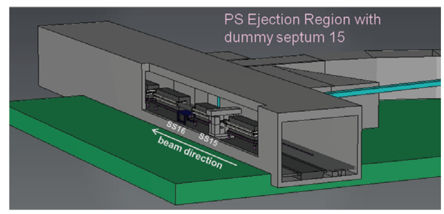

Figure 2: FLUKA geometry of the PS tunnel around the extraction region. The shielding of the dummy septum is visible in SS15.

The dummy septum blade allows to intercept particles that otherwise would be lost on the actual septum magnet. It must provide a reduction of the losses on the magnetic septum by a large factor (4 to 10). On the other hand the dummy septum should not increase the overall losses, *i.e.* should not interact with particles that would otherwise not be lost on the magnetic septum. The MTE extraction scheme comprises a slow closed bump around the dummy septum and magnetic septum by which the external island is pushed close to the blades of the two septa. Then a five-turns long closed bump generated by dedicated kicker magnets makes the external island to jump on the other side of the blade of the magnetic septum and get extracted. To shadow properly the extraction septum this has to correspond also to a jump on the external side of the dummy septum, allowing the losses to occur at the dummy septum. That device can also have advert effects on the other extracted beams, as studied in Ref. [6], as the fast extracted beams stay on the inside of the dummy septum blade. Therefore the blade position is tightly constrained and has to be optimized. Initial FLUKA studies have assessed the performance of the dummy septum by considering that a pencil beam would either hit the dummy septum or the actual septum [5]. Figure 3 shows these results in the form of the residual dose rate maps for both cases, assuming an irradiation time of 180 days at one-day cooling time. The result was very encouraging. In case of the dummy septum, the radiation field and the resulting activation is strongly reduced in SS16. This would allow any intervention to be carried out quickly, *i.e.* on the order of a few weeks, on the magnetic septum in case of failure, a crucial point for the operation of the LHC injector complex.

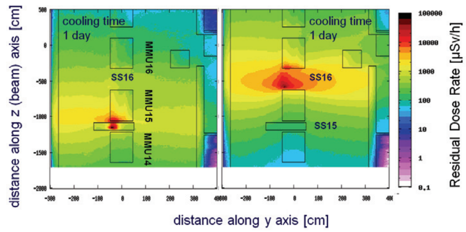

Figure 3: Residual dose rate maps for a pencil beam lost on the dummy (left) or on the magnetic (right) septum.

In order to find the optimum position for the dummy septum blade and to quantify the effectiveness of the shadowing method, a more realistic beam has been tracked with FLUKA, taking into account the optical properties of the PS main magnet located between SS15 and 16. The results are discussed in the next sections.

FLUKA STUDIES

Realistic Beam Distribution

The beam consists of two distinct parts: the islands and the core. The particles tracked by FLUKA represent the time-cumulated distributions of the beamlets as they move with time, following the rise of the closed fast bump from the internal side of the blade to the external side of the blade. These distributions are then normalized so that they represent a percentage of the total beam intensity. Fig. 4 displays the distributions representing the particles potentially interacting with the blade, for the islands (blue) and for the core (red). The distributions are shown on the upstream part of SS15, *i.e.* at the entrance of the dummy septum. The goal was to find the optimum blade position. An example of the 3 possible positions for the blade is shown in Fig. 4. The distributions comprise only a fraction of the total beam intensity as they represent only the beam during the rise time of the kickers. For the islands that fraction is 5.8% while the one for the core represents 1.1%.

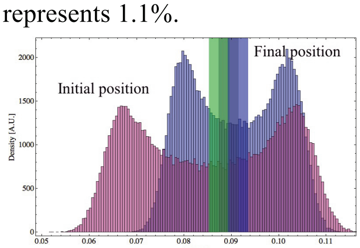

Figure 4: Beam distribution in SS15 (upstream) for the beam core (red) and for the outer island (blue). Different positions of the dummy septum blade are shown (colored vertical stripes).

FLUKA and MAD-X/PTC Tracking

Different geometries have been considered for the dummy septum blade. The blade thickness presently studied is 4.4 mm, the average width of the blade of the magnetic septum multiplied by the square root of the ratio of the horizontal beta functions in SS15 and 16. Five blade configurations have been considered (numbered with roman numbers and using as reference the position of the circulating beam in SS15). First three blade positions (inner edge of the blade): 85.3 mm (C-I), 87.3 mm (C-II) and 89.3 mm (C-III). Additionally we considered a blade located at 85.3 mm and rotated by 3 mrad toward the outside of the machine (C-IV), and a blade also located at 85.3 mm whose thickness was doubled (C-V). The aforementioned distributions are tracked with FLUKA in these different geometries. The tracking is done up to the end of SS15. Figure 5 shows the phase space distribution of the islands upstream (left) and downstream (right) of SS15. The gray rectangle represents the position of the blade for the configuration C-I. One can observe the effect of the interaction of the beam with the blade: it creates a hole in the distribution, as the blade length is about 3 nuclear interaction lengths for 14 GeV/*c* protons. Scattered particles are also observed. Due to the natural beam divergence we observe a rotation of the distribution. The hole in the distribution does not stay in alignment with the blade along the length of the drift space of SS15 (about 1 m). As the blade is 40 cm long, this has implications, as that means that the width of the hole cut in the beam will then be wider than the blade's width. Considering the mean angle of the beam at the entrance of SS15 that corresponds to an increase of 10 %.

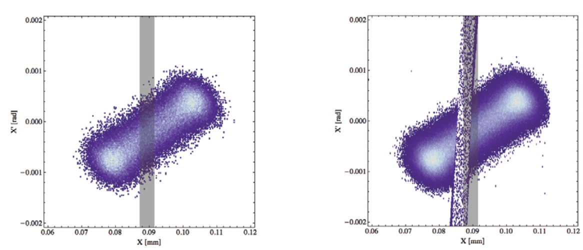

Figure 5: Horizontal Phase space showing the beam and the blade (gray vertical stripe) in SS15, upstream (left) and downstream (right).

The beam is then propagated in the main unit (MU) 15 between SS15 and 16. Thanks to the tracking code MAD-X/PTC, the particle tracking takes into account the full complexity of the PS MU (combined function magnet with nonlinearities). The losses occurring in SS15 and MU15 are then evaluated. The results are shown in Tab. 1. The results do not vary much for the three blade positions (configurations C-I, C-II and C-III) but are higher for the configurations C-IV and C-V. The higher losses for C-IV are explained by the positive angle of the whole beam at the entrance of SS15. As the blade is made to be more parallel to the beam, the interaction length is increased while the apparent width is lowered. The net effect leads to an enhanced fraction of interactions. The wider blade is inducing more losses, as one would expect. Losing slightly more than 0.6 % of the beam at the dummy septum is compatible with the device as the mechanical design was assuming losses of the order of 1%. A lower losses level, around 0.6 %, combined with

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the shielding surrounding the dummy septum is perfectly acceptable for that region of the machine, provided that it allows a suitable reduction of the losses in SS16.

Table 1: Losses in SS15 and MU15 for the 5 configurations.

C-I	C-II	C-III	C-IV	C-V
0.62 %	0.63 %	0.59 %	0.81 %	0.72 %

Figure 6 displays the phase portrait (left) and horizontal profile (right) of the tracked distribution at the entrance of SS16. One can clearly observe the role played by the optics from SS15 to 16. Indeed a mixing between position and angle induced the distribution to start filling the hole cut by the dummy septum blade.

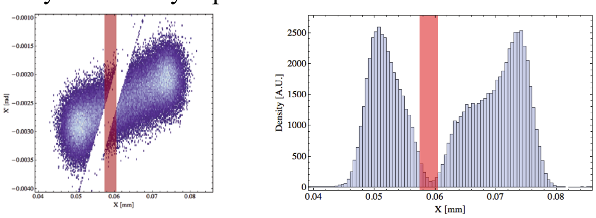

Figure 6: Beam distribution in phase space (left) and physical space (right) at the entrance of SS16. The blade of the magnetic septum is shown in red.

That means that the efficiency of the dummy septum cannot be perfect; the blade of the magnetic septum still intercepts a fraction of the beam. Nevertheless the reduction can be consequent, as presented in Table 2. We considered two possible positions for the blade of the magnetic septum: 55.5 mm, which is the operational value and 57.5 mm. The goal was to assess if a displacement of the blade toward larger amplitudes (57.5 mm) would improve the situation. Fig. 6 shows that the blade of the magnetic septum has to correspond to the minimum in the beam distribution. To do so the blade of the dummy septum has to be in position depending on the optics between SS15 and SS16. The results of Table 2 indicates that this correspond to 85.3 mm.

Table 2: Losses in SS16 for the 5 configurations considering the blade of the magnetic septum as a perfect absorber. The magnetic septum blade position is 57.5 mm (upper) and 55.5 mm (lower).

No blade	C-I	C-II	C-III	C-IV	C-V
0.52 %	0.14 %	0.27 %	0.45 %	0.07 %	0.08 %
0.55 %	0.29 %	0.47 %	0.56 %	0.20 %	0.28 %

Efficiency of the Dummy Septum

The results clearly show that the losses are lower with the blade of the magnetic septum located at 57.5 mm. The configurations C-IV and C-V exhibit losses below 0.1% but at the expense of increased losses in SS15 (Tab. 1), however these losses are still below 1%. From these two results the configuration C-I appears as the optimal candidate. It allows a reduction of the losses in SS16 by a factor 4, with losses in SS15 at a level comparable to the losses present in SS16 in the absence of the dummy septum. Further reducing the blade's amplitude is not possible due to the constraints imposed by the fast extraction of the other beams (AD, TOF, LHC) [6]. Nevertheless the results from C-IV indicates that for the best position of the blade (85.3 mm) it is still possible to reduce the losses in SS16 by rotating the blade, a possibility that has been taken into account in the design of the blade's support. That possibility shall be tested as it allows a reduction of a factor 2 in SS16 while increasing the losses in SS15 by only 30%. The different configurations can be tested during the commissioning phase, except for C-V. The losses in SS16 without dummy septum have been estimated from stray radiation measurements in the PS tunnel to be 1.0 ± 0.2 % of the total beam intensity. Simple analytical estimates assuming Gaussian beams and a septum blade acting as a totally absorbing medium gives 0.7 ± 0.1 %. The results obtained with the realistic distributions and the Fluka tracking account for 0.52 ± 0.05 % of losses. The discrepancy between theory and measurement is mainly due to the fact that the measurements where done during a commissioning phase, unfavorable in term of beam losses, while the theory supposes an ideal setup.

CONCLUSION

Coupled MAD-X/PTC and FLUKA simulations have been performed, comprising the complexity of the tracking in the PS main unit and the complete geometry modeled in FLUKA. The losses in SS15 and SS16 are obtained for different positioning of the blades of the dummy septum and the magnetic one. An optimized configuration has been obtained with a dummy septum blade 4.4 mm thick located at 85.3 mm and a magnetic septum blade located at 57.5 mm. That configuration features a reduction of the radiation field and resulting activation by a factor 3-6 in the whole environment of the magnetic septum in SS16, so that the resulting values are smaller by a factor of 2 than for the present CT operation. The total absolute beam losses are not changed.

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