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MULTI-TURN STUDY IN FLUKA FOR THE DESIGN OF CERN-PS INTERNAL BEAM DUMPS

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Abstract

The CERN Proton-Synchrotron (PS) accelerator is currently equipped with two internal beam dumps in operation since the 1970s. An upgrade is required to be able to withstand the beams that will be produced after the end of the LIU (LHC Injector Upgrade) project. For the design of the new dumps, the interaction and transport of beam and all secondary particles generated has been simulated using FLUKA.

The working principle of the PS internal beam dump is peculiar compared to the other beam dumps in the CERN accelerator complex: a moving dump intercepts the circulating beam during few milliseconds similarly to a fast scraper. The moving dump shaving the beam, the multi-turn transport of beam particles in the PS accelerator, and a time-dependent energy deposition in the dump were modeled. The methodology used in the FLUKA simulations and the comparison with experimental results are presented.

INTRODUCTION

The CERN Proton-Synchrotron (PS) is the first CERN synchrotron and has been in operation since 1959. One of the main operational and safety systems present in any particle accelerator, and so the PS, is the beam dump system, with the goal of stopping or removing the circulating beam in a safe and controlled way. It can be an internal dump, when placed inside the accelerator structure, or external, being required in this case the extraction of the beam before dumping. In the case of internal dumps, the usual way they operate is through an electromagnetic deflection of the beam towards a massive static dump. However, in the CERN-PS a moving intercepting device enters in the circulating beam in order to absorb the beam particles.

This uncommon dumping mode among the CERN accelerator complex offers challenges from the design point of view. On one hand, since the device has to be moved, its weight must be minimized. On the other hand, a massive object is required to absorb as many particles as possible to reduce the radiation damage in other elements of the machine. A compromise between both requirements has been reached in the design of the PS beam dump core presented in this paper and in Ref. [1].

The mechanical movement of the dump to encounter the beam is slow in comparison to the revolution frequency of the circulating beam. This causes the absorption of the beam pulse to occur in a multi-passage mode during few milliseconds. In similar way to a scraper shaving the beam, the dump progressively absorbs the beam.

Currently, there are two identical internal beam dumps installed in the PS accelerator in straight sections 47 and 48. They were designed in 1974 and have been in operation since then with no relevant operational failures. With the advent of the LHC Injectors Upgrade [2] and in order to fulfill the established beam requirements, the current dumps will become obsolete as they can not withstand the increase in beam intensities expected for the future operational regime (see Table 1). Therefore, an upgrade of the dumps was required.

Table 1: Beam parameters for the main pre- and post-LIU beam types at odd straight sections of the PS ring for proton beams at extraction momentum (26 GeV/c) [3]

Beam type	**Beam size (mm)**		**Beam Intensity**
	σ_x	σ_y	(10^{13} p/pulse)
LHC 25 ns 2015	1.85	0.98	0.87
BCMS 2015	1.55	0.65	0.58
HL-LHC	1.74	0.87	2.4
HL-BCMS	1.65	0.77	1.6

MULTI-TURN SIMULATIONS

The tracking of beam particles along the full PS ring is needed to reproduce the beam dumping process in a realistic manner. A simulation including the accurate tracking of beam particles along the ring and the detailed beam-dump interaction would be the ideal approach. However, that procedure would require unacceptably long computational times. Therefore, a simplified model of particle tracking in the accelerator was adopted. It is based on a 5-dimensional particle tracking including, apart from the spatial and time coordinates of the particles, the PS horizontal dispersion.

The model was implemented using a set of tracking routines which were coupled to FLUKA [4, 5]. FLUKA is a Monte Carlo code to simulate beam-matter interaction and particle transport. It is widely used at CERN for many applications such as beam-machine interactions, radiation protection calculations or radiation effects to electronics among others. In the present case, FLUKA is used to simulate the interactions between the beam and dump material in a multi-passage of beam particles by the dump location by including the tracking routines.

The mechanism of particle tracking simulations is sketched in Fig. 1. The PS accelerator ring is divided in two main sections:

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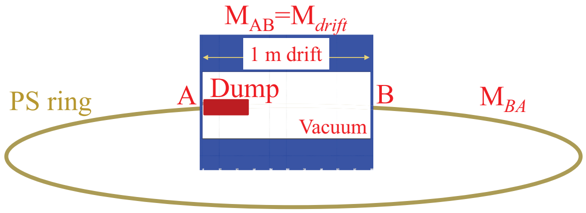

Figure 1: Illustration of the model used in FLUKA for the beam particle transport along the PS ring.

1. a 1-meter-long drift corresponding to the dump location (from point A to B in Figure 1),
2. the rest of the PS ring (from point B to A).

The tracking of beam particles starts from point A and particles are transported using FLUKA through the first section (1-meter-drift) only when a possible crossing with the dump may happen. This is done by comparing the dump position and the particle trajectory at every machine turn. In this way, the computational time per primary particle is reduced. Then, after being transported, particles arrive to the end of the drift, point B. There, if they fulfill the aperture and acceptance restrictions of the machine that would prevent them from reaching point A, they are transported along the rest of the ring (from B to A). This is done by using the M_{BA} transport matrix, which is obtained from the One Turn Matrix (OTM) and the 1-meter-drift matrix (M_{AB}) as:

$$M_{\mathrm{BA}} = M_{\mathrm{AB}}^{-1} \times M_{\mathrm{OTM}} \qquad (1)$$

where M_{AB} and M_{BA} are, respectively, the matrices transforming the particle coordinates from A to B and B to A, M_{AB}^{-1} the inverse matrix reproducing the transport backwards of the particles from B to A and M_{OTM} the One Turn Matrix. The matrices were computed starting from the PS optics model and were parametrized with respect to the PS horizontal and vertical tunes. The particle matched distribution considered for the tracking was obtained from the optics functions at the dump location (β_{DUMP}, α_{DUMP}), the horizontal dispersion ($D_{\mathrm{X,DUMP}}$) and the beam parameters (transverse emittances and RMS energy spread).

The simulation of the beam-dump interaction in the PS ring has been implemented as a dynamical process. While the beam particles travel along the ring, the dump is moving vertically to encounter the beam. Therefore, the position of the dump is updated at every turn. An average vertical speed of 0.8 m/s was obtained experimentally for the current dumps. For the future dump, the speed was determined from mechanical simulations of the dump moving mechanism and was found similar as for the old dump.

Beam Shaving Mode

A 26 GeV/c proton takes about 2.1 µs to complete a full turn in the PS ring. During that time the dump moves vertically 1.68 µm. Since the beam profiles have a 1 σ vertical size of ≈1 mm (see Table 1) the total beam size is of the order of 6 mm (≈ 6σ). Therefore, since the dump speed is 0.8 m/s, the dump needs around 6-9 ms to cross the full beam profile, assuming the beam particles not alter their transverse position turn after turn during the beam shaving, that is being the machine tune an integer value. In this way, the dump is acting as a fast scraper, absorbing the beam during few milliseconds in a shaving mode.

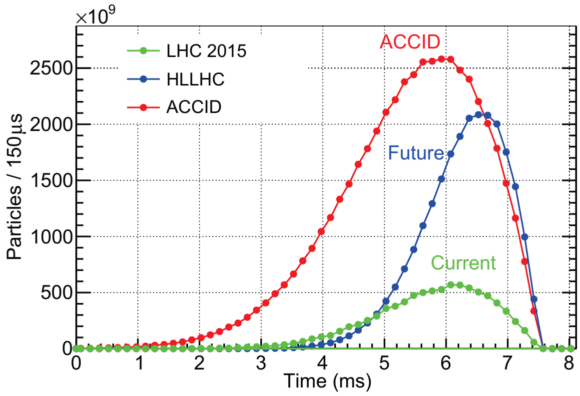

Figure 2: Time evolution of the number of beam particles interacting with the dump for the most representative pre- and post-LIU beam types.

This result can be observed in Figure 2. The time evolution of the absorption of beam particles after the interaction with the dump obtained from the FLUKA simulations is plotted for three chosen beam types. The green curve corresponds to the current LHC production beam (LHC 2015) meanwhile the blue and red curves show the two more demanding future beams: the HL-LHC and an ACCIDental scenario defined as the beam with highest intensity expected. The increase in beam intensity after the LIU upgrade is clearly visible since the curves are normalized per beam pulse.

RESULTS

The multi-turn approach implemented in the simulations needed to be experimentally validated. Therefore, an experimental study in form of a Machine Development (MD) was performed, by dumping beams with one of the current internal dumps and recording the time evolution of the beam intensity during the process.

Two different beam types were dumped and their properties are given in Table 2. The machine tunes, the 1σ normalized transverse beam emittance, and the beam momentum for each beam type were taken and used in the FLUKA simulations.

Once the circulating beam was established in the PS (constant closed orbit and tunes), the PS internal dump was triggered. The time evolution of the beam intensity while dumping was experimentally recorded. The experimental transverse beam profiles were measured using wire scanners. They were found to be in good agreement with the simulated beam profiles.

Table 2: Beam properties for the MD test. Beam momentum spread was considered to be 0.4×10^{-3}.

Beam type	**Beam momentum** (GeV/c)	**Machine tunes** Q_h	Q_v	**Emitt.** (norm. 1σ) ϵ_h (mm mrad)	ϵ_v
LHC	26.4	6.22	6.27	3.34	3.04
TOF	2.14	6.13	6.27	27.37	6.0

Figure 3 shows the comparison of the measured and simulated beam intensity decrease while dumping. Longer dumping times were found for the TOF beam as a consequence of its larger geometrical beam emittance, see Table 2. The experimental and simulated curves are in sufficiently good agreement in both cases. This result supports the approach followed in the simulations, including the simplified particle tracking in the ring and the assumptions made on the beam dumping process.

Energy Deposition in Dump Core

The design of the PS Internal Dump core was studied using the multi-turn approach in FLUKA previously described. As an output of the simulation, energy-power-density maps were obtained. These maps were later used as input to perform the thermo-mechanical studies described in Ref. [1].

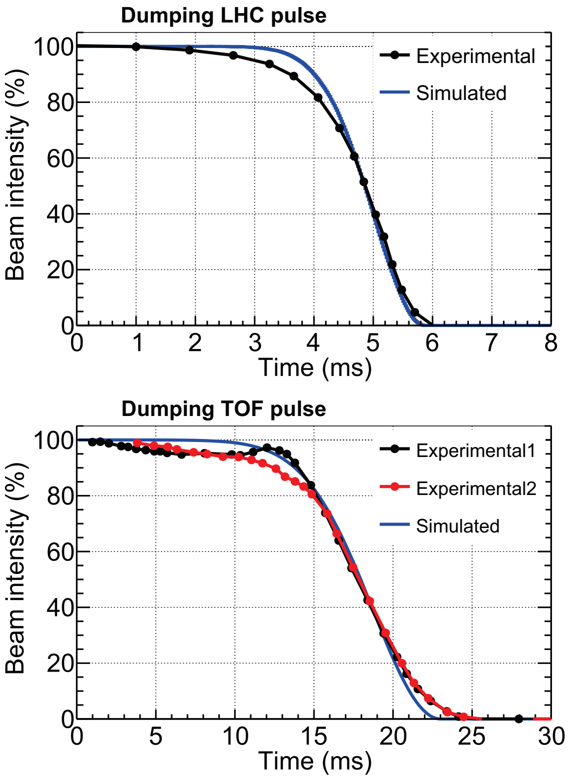

Figure 3: Comparison of the experimental and simulated beam-intensity during beam dumping for LHC (up) and TOF (down) beams. The main properties of each beam type are summarized in Table 2.

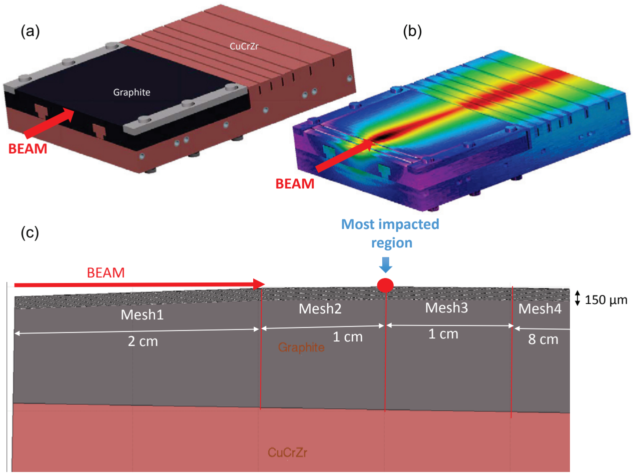

Figure 4: Geometry of PS Internal dump. (a) 3D view of the dump core. (b) Energy density map obtained after a beam impact. (c) Longitudinal section showing the spatial meshes for evaluation of peak energy density.

Figure 4 shows the latest geometry of the dump core. The upper frontal face of the dump follows a curved shape at the impact location of the beam, in order to spread out the energy absorption and minimize the peak energy density. Figure 4(c) shows a longitudinal section at the dump center location to show how the curved shape is simulated in FLUKA and how the spatial meshes are allocated. Several spatial meshes recording the energy deposition were needed for a proper peak energy density evaluation and to properly cover the frontal curved shape of the dump with fine vertical bins as shown in Fig. 4.

The total dumping time of few milliseconds was divided in time steps of 150 µs length each and the power deposited in the dump was recorded in several 3D spatial meshes. In total six spatial meshes and up to 55 time steps were recorded, leading to more than 300 maps of energy density deposited were recorded per beam type. Those maps were then used as input for the thermo-mechanical studies described in more detail in Ref. [1].

CONCLUSIONS

The internal beam dumping process in the PS ring at CERN has been presented. The PS internal beam dumps need to be upgraded to withstand post-LIU beams. For the design studies of the new dumps the beam particle transport in the machine is required. A simplified model has been implemented in FLUKA in order to reproduce the particle tracking in the ring in an accurate enough way while reducing significantly the computational time required.

An experimental test of the PS beam dumping was performed. The time evolution of the beam intensity during the dumping process has been compared to simulations for two different cases. The agreement found supports the procedure adopted in the FLUKA simulations. The multi-turn approach, once experimentally validated, was applied for the thermo-mechanical studies for the design of the dump core. The maps of energy density absorbed by the dump core were recorded in time steps of 150 μs each to cover the full dumping time (lasting few milliseconds). Six spatial meshes were used to properly evaluate the energy density deposited in the dump at every time step. In total, more than 300 energy density maps were obtained per beam type.

Those maps were used as input information to perform detailed thermo-mechanical studies of the dump core. All this procedure lead to find a suitable design of the dump core able to withstand the demanding beam conditions required for post-LIU beams.

REFERENCES

[1] G. Romagnoli *et al.*, "Engineering design and prototyping of the new LIU PS internal beam dumps", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, May 2018, paper WEPMG001, this conference.

[2] The LHC Injectors Upgrade (LIU) project, `https://espace.cern.ch/liu-project/default.aspx`

[3] R. Steerenberg, and D. Cotte, "PS beam spot sizes for the design of new internal beam dumps", CERN Technical Report EDMS-1612293, 2017.

[4] G. Battistoni *et al.*, "Overview of the FLUKA code", *Annals of Nuclear Energy* 82, 10-18 (2015).

[5] A. Ferrari, P.R. Sala, A. Fassò, and J. Ranft, "FLUKA: a multi-particle transport code", *CERN-2005-10, INFN/TC_05/11, SLAC-R-773*, 2005.