BEAM LOSS MAP SIMULATIONS AND MEASUREMENTS IN THE CERN PS

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Abstract

Numerical tools providing detailed beam loss maps, recently developed for the design of the Large Hadron Collider (LHC) collimation system, were adapted to low energy synchrotrons. Using a MADX optics sequence model, these tools are able to track a large number of particles with SixTrack and interact with a realistic aperture model to simulate particle losses all around the ring. Finally the comparison between the dedicated simulations and measured proton loss pattern at the CERN PS showed good agreement between them.

INTRODUCTION

Within the framework of the LHC luminosity upgrade, scenarios for a new injector chain complex are being proposed, including the replacement of its oldest component, the CERN Proton Synchrotron (PS), with a new ring, the so called PS2 [1]. Its operational energy ranging from 4 to around 50GeV, the new ring does not necessitate the use of superconducting magnets thus avoiding quench issues due to beam losses. Even in that case the control of beam losses by designing a collimation system is necessary for activation and maintenance issues [2]. Both designs, lattice and collimation system, should be carried out simultaneously since the second will constrain the optics and refine the aperture requirements along the ring.

For the LHC collimation system design, robust numerical tools were used, providing detailed beam loss maps around the ring [3]. These tools cannot be directly used to low energy synchrotrons as the PS2, not only because of the energy dependence of particle-matter interaction but also because of the approximations that are usually assumed in the magnetic field when tracking on large rings like the LHC. In this respect benchmarking studies are necessary to check the validity and accuracy of the simulations especially with respect to real measurements, similar to the ones which were carried out at the SPS [4]. In this paper, the main features of the numerical tools are reviewed and in particular the issues arising when tracking particles at low energies. The reliability of the simulations are then tested by comparing the modeled beam loss maps with measurements carried out in the actual PS during the Continuous Transfer (CT) extraction [5].

BEAM LOSS SIMULATIONS

The LHC beam loss simulation tools consist of a 6D single particle tracking through a MADX [6] thin lens lattice, using SixTrack [7] combined with scattering processes of particles within the collimators jaws and an interaction with a detailed aperture model of the studied ring. A detailed documentation can be found in [8]. In what follows we concentrate with issues raised when dealing with low energy rings.

Tracking through a Thin Lens Model

SixTrack is a 6D element by element single particle tracking code, taking into account magnet non-linearities up to very high orders. Although the linear elements can be treated as thick elements, the necessity of tracking large numbers of halo particles over thousands of turns would require excessive CPU resources. Due to this a thin lens model approximation is used instead [3].

MADX includes a module converting a thick lens into a thin lens lattice. Whenever this conversion is done in a dipole, all fringe field effects are neglected because of technical symplecticity issues. Only the edge focusing from the pole face angles of the magnets can be taken into account with a special MADX module representing thin lens quadrupole kicks at each dipole side. The non-linear terms which have a "quasi-sextupole" nature involving second order terms of positions but also of momenta in the equations of motion are thus absent in the thin lens model. These terms can be "faked" by thin lens sextupoles in order to adjust the chromaticity which is largely affected. In Fig. 1, we present the tunes computed by MADX during the PS CT extraction by following the real thick element calculation with the realistic pole face angles in the PS dipoles, a thick element model without the pole face angles but with a thin quadrupole kick modeling them and finally the same after the thin lens conversion of the lattice. In all the cases, the tunes are the same. The good representation of on-momentum transverse dynamics is also visible in Fig. 2 where the betas for all three cases are pictured with no visible differences.

On the other hand, by dropping the non-linear terms, there is a certain influence in chromaticity, as represented in Fig. 3. The inclusion of a thin sextupole and rematching the chromaticity to the initial value fixes the problem but the real solution would be to do real thick element tracking using PTC [9]. In this respect, several tests were made, but still some technical problems have to be solved regarding the interaction of PTC tracking with an aperture model and the scattering simulations.

Scattering Processes

The K2 [10] scattering code is used to simulate the interaction of particles with collimators and other material

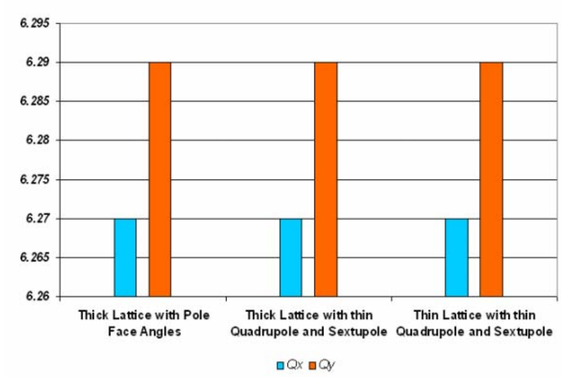

Figure 1: Horizontal and vertical tunes for different lattice configurations during the PS CT extraction.

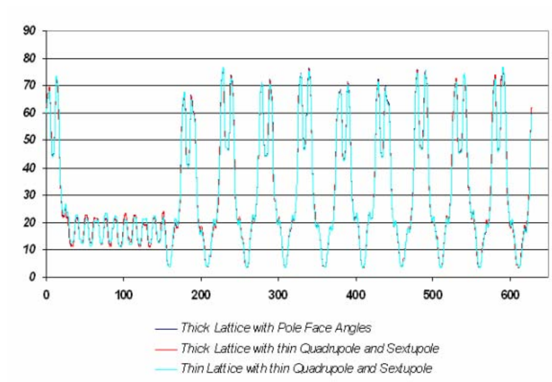

Figure 2: Horizontal and vertical beta functions for different lattice configurations during the PS CT extraction.

in the case of the LHC. The scattering mechanisms included (nuclear interactions with finite cross section, multiple Coulomb scattering and ionisation) [11] depend in a different way on the energy [12]. Some considerations should be taken into account as K2 is set for LHC energies (450GeV-7TeV) and PS2 will operate in the ranges between 4 and 50GeV. Especially the stopping power is no longer constant and for proton-nucleon collisions, the energy dependence of the cross section is not linear in a logarithmic scale in this range as it is the case for higher energies. The code was modified accordingly in order to include this latter difference. No changes have been introduced for interaction processes for which the variation with energy is negligible.

Apart from the internal scattering algorithm, it is possible to generate a distribution by an external scattering code and feed it back to Sixtrack for tracking and comparison with the aperture model. The final loss location is determined through this comparison. In order to get a very good accuracy with respect to the longitudinal position, the lost particle is backtracked until the exact loss location is found. The present version of the code allows an accuracy of 10mm in the loss location.

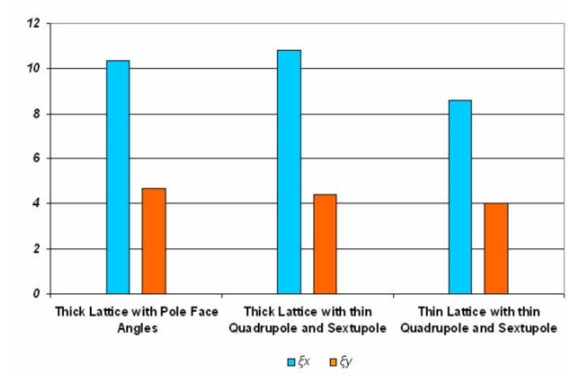

Figure 3: Horizontal and vertical chromaticities for different lattice configurations during the PS CT extraction.

BEAM LOSS SIMULATIONS DURING CT EXTRACTION

The simulations will be compared with measurements in the PS during CT extraction. In this case, a high intensity 14 GeV proton beam is extracted in 5 turns from the PS. The beam is sliced 5 times passing through an electrostatic septum located in straight section 31 and extracted in the next turn by a magnetic septum in straight section 16 (the PS is composed by 100 combined function magnets and 100 straight sections).

The data presented on Fig. 4 correspond to measurements made with Beam Loss Monitors (BLMs) located in each section. In principle, some discrepancies in the comparison of measurements and simulations are expected because of the position of the BLMs which are alternating between the internal and external location of the combined function magnets. These measurements were performed in the middle of the 2006 run.

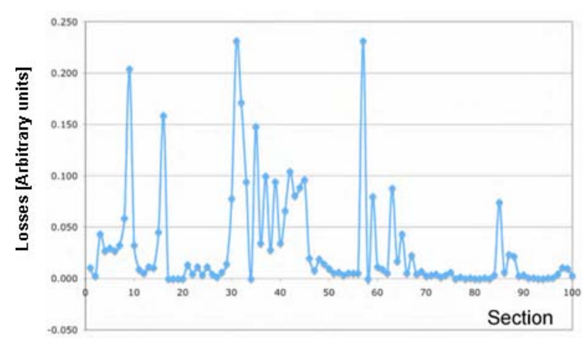

Figure 4: Loss measurements from BLMs distributed along the 100 PS sections.

These losses were identified as scattered particles by the electrostatic septum blade during the extraction process and lost around the ring [13]. In this respect, two approaches were followed: First the scattered distribution coming from septum 31 was produced by the MonteCarlo code MARS [14]. The coordinates were recorded at the end of the blade and shown in Figure 5. The simulation integrated the process over 5 turns. The distribution is also symmetric in angles and was cut at 10GeV due to the limitation of SixTrack in tracking off-bucket particles.

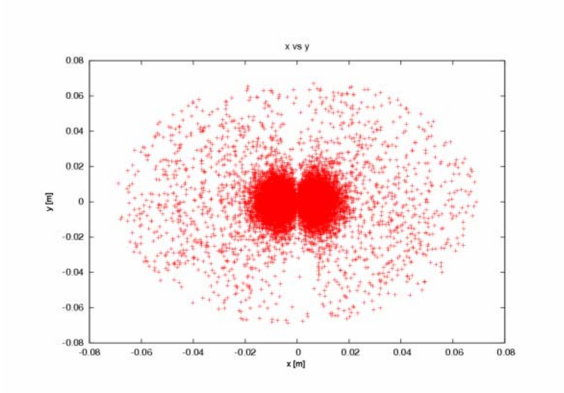

Figure 5: X and Y coordinates of the scattered distribution at the end of the septum.

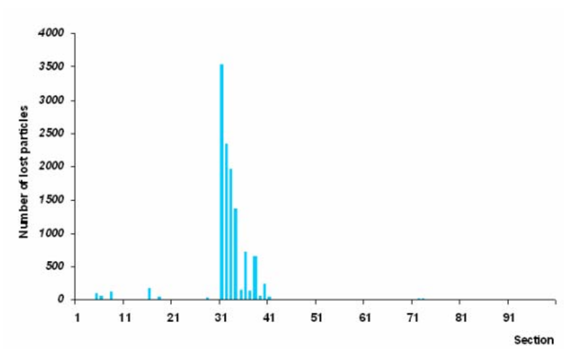

Figure 6: Beam loss patterns tracking an external distribution generated by MARS.

In the second approach, the electrostatic septum used in the CT Extraction is modeled by one collimator jaw located in the horizontal plane in the outer wall of the vacuum chamber. In this way, K2 is used for simulating the scattering processes. As the material of the septum (Molybdenum) was not initially foreseen by K2, the relevant parameters (atomic numbers, differential cross sections of the different processes, etc.) were included in the program. The tracking is done for around 100 turns.

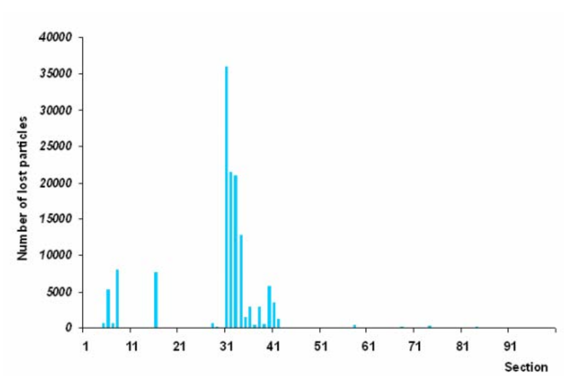

Figure 7: Beam loss patterns modeling the septum by a collimator jaw.

Two aperture limitations are located in sections 16 and 31. The first one corresponds to the magnetic septum and the second is the already mentioned electrostatic one. From Figures 6 and 7 where the loss location around the ring following the two approaches are simulated, big amount of losses are found in both regions. Qualitatively, the measured losses around the ring are well represented by both simulations. Some discrepancies may be attributed to the real beam loss monitor location with respect to the losses but also to some simplifications of the model as the non-inclusion of the septum kick to the scattered particles or the closed orbit distortion and the fact that the ring elements apart the collimator (septum) are considered as black bodies absorbing the whole amount of lost particles.

These good agreement from both simulation approaches give us confidence for the application of the numerical tools in the design of the PS2 collimation system.

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