BEAM LOSSES IN THE PS DURING CT EXTRACTION

S. Gilardoni[@], J. Barranco[#], CERN, Geneva, Switzerland.

Abstract

The proton beams used for the fixed target physics at the SPS are extracted from the PS at 14 GeV/c in five turns, using a technique called Continuous Transfer (CT). During this extraction, large losses are observed in straight sections were the machine aperture should be large enough to accommodate the circulating beam without any loss. These losses are due to particles scattered by the electrostatic septum used to slice the beam and defocused by a quadrupole used during the extraction. Simulations and experimental results are presented.

INTRODUCTION

The proton beams used for the fixed target physics at the SPS (Super Proton Synchrotron) are extracted from the PS (Proton Synchrotron) at 14 GeV/c in five turns using a technique called Continuous Transfer (CT)[1]. During this extraction, large losses are observed in straight sections were the machine aperture should be large enough to accommodate the circulating beam without any loss. These losses are due to particles scattered by the electrostatic septum used to slice the beam and defocused by a quadrupole used during the extraction. These losses limit the maximum intensity deliverable to the SPS for fixed target physics, like for the CERN to Gran Sasso (CNGS) neutrino program, because of the large irradiation of the site outside the PS tunnel and at the CERN fence.

Simulation and experimental results are presented as update of the study of [2].

CONTINUOUS TRANSFER: CT EXTRACTION

During the CT extraction, the horizontal tune of the PS is set to 6.25, namely to obtain a phase advance per turn of 90°. In such conditions, a part of the proton beam is pushed by a slow and a fast bumps beyond the blade of an electrostatic septum. The sliced beam that receives the kick of the electrostatic septum is extracted during the current machine turn, while the rest is extracted with the same mechanism within the next 4 turns. The different bumps are set in such a way that the five beam slices feature the same intensity.

Among the different elements of the PS, which is composed by 100 combined-function magnets arranged in a FDODF lattice and interleaved by 100 straight sections (SS, numbered from SS00 to SS99), the ones used for the CT extraction are (see Fig. 1):

- Slow bump (BSW31) around the electrostatic septum, created by two magnets in SS27 and SS35, and used together with the two fast kickers (BFA9 and BFA21) to push the beam beyond the electrostatic septum.
- The electrostatic septum (SEH31) used to impart an extra kick to the beam slice for the extraction.

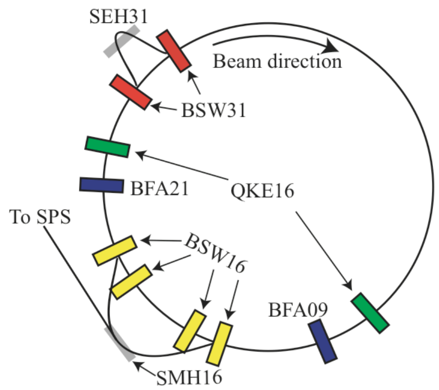

Figure 1: Scheme of different elements used during the CT extraction.

- The slow bump (BSW16 composed of four magnets in SS12, SS14, SS20 and SS22 respectively) used to direct the beam, together with the magnetic septum (SMH16), in the transfer line towards the SPS.
- Two quadrupoles located in SS25 and SS05, which form the QKE16, used to distort the optics of the machine between them hence having a large horizontal beta at the septum SEH31 and practically zero dispersion, as shown in Fig. 2.

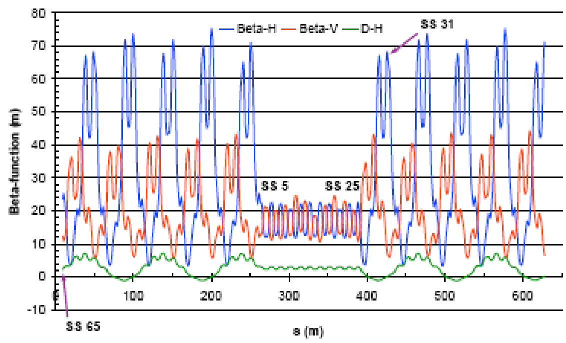

Figure 2: PS optics perturbed by the QKE16 during the CT extraction [11].

During the slicing/extraction process losses are observed, as expected, downstream of SS31 and in the extraction region around the SS16, as shown in Fig. 3. However, losses are present also in non-expected SS, like in the injection region, from SS39 to SS46, and

[@] Simone.Gilardoni@cern.ch
[#] PhD student at Universitat Politècnica de Catalunya, Barcelona, Spain

under the so called the PS-Bridge, between SS05 and SS10.

The machine shielding around the mentioned sections is not sufficient, causing large irradiation outside the PS tunnel, and hence limiting the maximum intensity deliverable to the SPS.

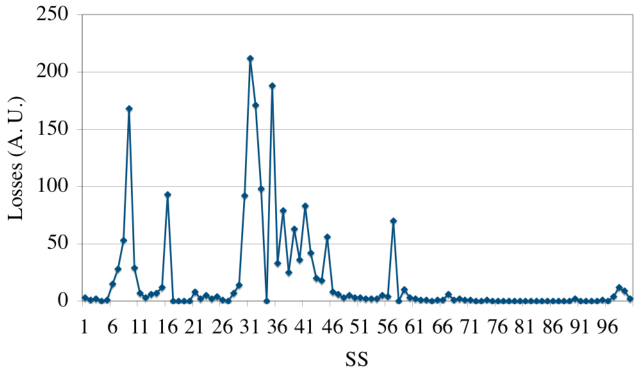

Figure 3: Beam loss pattern as recorded by the ACEM detectors for a moderate intensity CNGS beam.

The beam loss monitor system

The beam loss monitor (BLM) system is composed by 100 ACEM detectors (Aluminium Cathode Electron Multiplier [3]) mounted on top of the main magnets. Due to the position chosen in the past (the system dates back to the middle '80s) and the large variation of the signal with the primary proton energy, it is practically impossible to correlate the amount of protons lost in the machine with the signal recorded by the BLMs. Most of the losses in the PS are in the horizontal plane, whereas the BLMs are mounted on top of the bulky iron yoke of the main magnets (see Fig. 4), just after each SS. Since some straight sections are composed by a simple beam pipe, while some others are completely filled by magnetic elements, particles lost in different SS will create a very different secondary shower reaching the loss detectors.

To complicate even more the picture, the BLMs are installed on different sides of the main magnets, in some sections facing the inside of the ring, sometimes the outside, following the quasi-regular pattern of the four magnet types which compose the PS lattice. For these reasons, the BLM system is used during operation to detect malfunctioning of the machine, more than as a real protection system, obtained by comparing online a given loss pattern with the reference one.

The pattern of the losses observed with the system can tell something about the region where the losses occurs, whereas it is not possible for example to deduce the ratio of beam lost between two different sections of the machine. It is not even possible to deduce if the loss is produced in one of the main magnets or in the straight sections, being the BLM mounted at the entrance of the magnet unit.

Figure 4: PS main magnet units. The ACEM BLM detectors are the orange cylinders mounted on top of the magnets.

The aim of the simulations presented in the following is to reproduce qualitatively the observed loss pattern but not to quantify the beam loss detected by the BLMs. This would require a detailed simulation of the secondary shower developing in a large fraction of the main magnets, and goes beyond the purpose of this study.

Loss mechanism: principle and simulations

During the pulsing of the extraction elements, losses are identified in SS05-SS10 during the rise of the BSW31, before actually the beam is sent completely beyond the SEH31 to be sliced. This would indicate that the particles lost are the results of the interaction of the circulating beam with the about 150 μm thick, 1.8 m long Molybdenum septum blade. The multiple scattering introduced by the blade material results in an extra angular kick to the particles, which then follow a large amplitude orbit, so large that when they arrive at the location of the quadrupole in SS05 they are basically extracted.

Two simulations have been developed to understand this loss mechanism. The goal of the simulations is to reproduce qualitatively the observed loss pattern, but also to prove that the simulations are precise enough to predict a possible alleviation of the problem. The goal is also to prove that these tools could be used in the future for the study of losses in low energy synchrotrons like the PS2 [4].

Two methods have been implemented:

- The interaction of the circulating beam with the septum blade is simulated by the MARS[5] Monte Carlo code. The scattered particles are then tracked in the PS lattice and a simplified aperture model using MAD8[6]. This simulation does not take into account the fast bumps and consider only one turn.
- The interaction with the septum blade is modelled using K2[7] and the tracking is performed by SIXTRACK[8,9]; K2 is a Monte Carlo interaction module developed for the LHC collimation studies, hence the physics has been adapted for the PS energies. A bunch of particles is tracked through a thin lens lattice (generated by MADX[10]), undergo scattering processes in the septum blade (K2) and, finally loss locations are determined by means of an external program and the detailed aperture model. Some approximation introduced by the thin-lens model had to be corrected: the high order terms of edge effects in fact are not symplectic in thin lens. Thin multipoles were included and tune and chromaticity matching were performed to take into account correctly the end-field effects of the main magnets. This simulation tracks particles on the five extraction turns, considering also the fast bumps.

Simulation Results

Fig. 5 and Fig. 6 present the results for the two simulations. The patterns of the losses versus the SS are qualitatively very similar, even though the two simulations do not have the same normalisation. An eventual discrepancy in the simulated pick ratio with respect to the BLM data is not surprising.

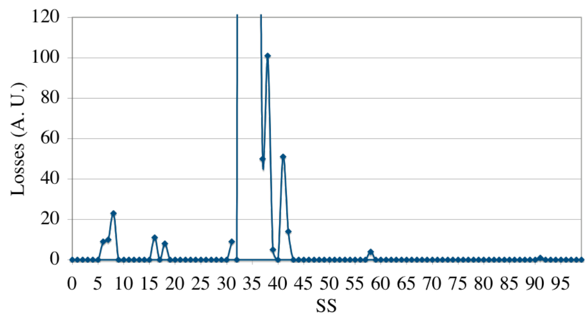

Figure 5: Simulated losses with simplified method versus SS. The vertical scale represents the number of proton lost per section non-normalised by the number of primary protons.

As described in the previous section, the BLM system is not meant to provide precise data about the amount of proton lost, whereas the results of the simulation is a pure counting of protons which hit the machine aperture.

Other discrepancies might be due to the fact that in reality the scattered particles might re-interact with other aperture restrictions in the machine and being furthermore deviated, whereas in the simulation those supplementary restrictions are considered as pure absorbing surfaces. Moreover, the simulations do not take into account the propagation of the secondary particle shower, which might displace the maximum of the losses by one or two SS.

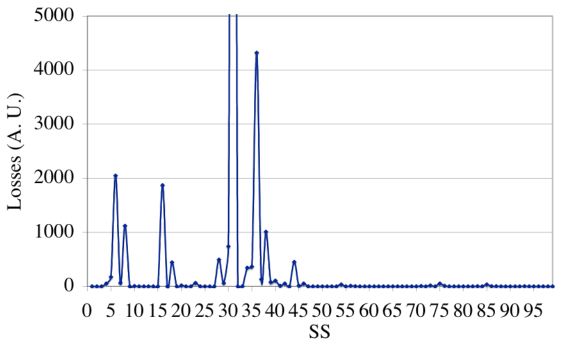

Figure 6: Simulated losses with more refined method versus SS. The vertical scale represents the number of proton lost per section non-normalised by the number of primary protons.

Considering all of this, the simulation is precise for prediction of the losses within ±1 SS with respect to what the BLMs will detect.

LOSSES DISPLACEMENT

Since it has been shown that the two simulations confirm the loss mechanisms, it is impossible to avoid these kind of losses without changing completely the extraction scheme, like it is foreseen in the future Multi Turn Extraction (MTE, see [11]). The only viable solution is to displace the losses in a better-shielded part of the machine, where the tunnel radiation shield thickness is enough. This can be done, as shown by

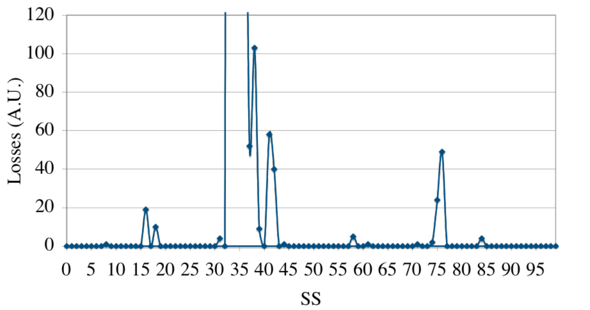

Figure 7: Simulated losses with the simplified method with the losses displaced thanks to the new quadrupole.

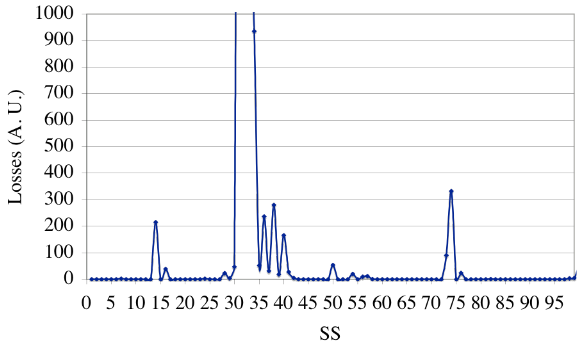

Figure 8: Simulated losses with more refined method with the losses displaced thanks to the new quadrupole.

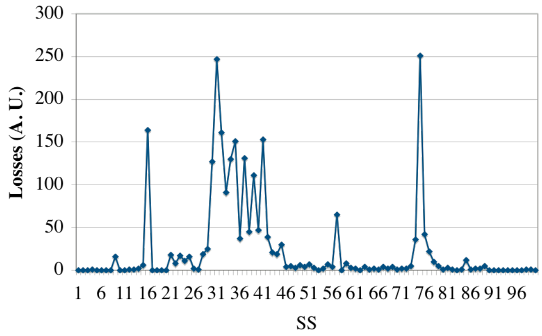

Figure 9: Measured losses displaced thanks to the new quadrupole.

simulations (see Fig. 7 and Fig. 8), by installing a new quadrupole in SS73, 4π in phase advance before the quadrupole in SS05. The new extraction scheme would be then unchanged, apart that instead of powering the QKE16, one should power the quadrupole in SS25 and the one in SS73. This should remove completely the losses in SS05-SS10 and bring them in SS73-SS78. During the shutdown 2006-2007 a set of new quadrupoles has been installed, in such a way that four quadrupoles could be available for the extraction. Tests powering the quadrupoles in SS25 and SS73 confirmed the simulation prediction.

As shown in Fig. 9, in fact, the losses appear to be displaced in the predicted sections, without changing the extraction efficiency. Actually, this new extraction configuration has been retained for the 2007 run, in particular during the high intensity operation with 2200e10 proton per pulse extracted for the CNGS and the SFTPRO (Fixed Target Physics at the SPS) beams, and it will be used for the 2008 run.

A further optimisation has been done by powering the four available quadrupoles at the same time, the group SS25-SS73 at full current while the group SS25-SS05 at one third of the nominal one. This, as predicted by simulations, results in the sharing of the losses between SS05-SS10 and SS73-SS78, as shown by the small peak appearing in SS09 in Fig. 9. Moreover, it has been experimentally observed that the extraction efficiency improved, thanks probably to a large beam envelope at the septum location.

CONCLUSIONS

Losses during CT extraction from the PS are generated by the beam interaction with the electrostatic septum used to slice the beam in 5 turns. These losses cannot be avoided but only displaced in sections of the machine further away from the CERN fence and where the tunnel radiation shielding is more effective.

Simulations and experiments confirm the mechanism of losses and the loss pattern observed. The proposed scheme to displace the losses, once implemented, showed to be well in agreement with the simulations, with the losses moved in the predicted locations.

New simulation tools developed using SIXTRACK and K2 adapted to low energy synchrotrons plus the proper aperture model show to be suitable for the study of the mentioned losses.

ACKNOWLEDGMENTS

The authors are thankful: to the PS operation team for the support during the experimental measurements, to G. Arduini, M. Giovannozzi, B. Jeanneret and Y. Papaphilippou for the fruitful discussion, to O. Berrig for providing the detailed aperture model of the PS, to R. Brown, S. Baird, the AB/PO and AB/CO CERN groups for implementing the new quadrupole configuration.

REFERENCES

[1] C. Bovet et al., "The fast shaving ejection for beam transfer from the CPS to the CERN 300 GeV machine", PAC1973, edited by D. W. Dupen (IEEE, New York, 1973).

[2] J. Barranco et al., "Beam loss map simulations and measurements in the CERN PS", PAC07

[3] V. Agoritsas et al., "A microprocessor-based system for continuous monitoring of radiation levels around the CERN PS and PSB accelerators", NIMA 247 (1986), 44-49

[4] W. Baartmann et al, "Optics considerations for the PS2", PAC07, Albuquerque, USA

[5] N.V. Mokhov, Fermilab-FN-628 (1995). O.E. Krivosheev, N.V. Mokhov, Fermilab-Conf-00/181 (2000). N.V. Mokhov, Fermilab-Conf-03/053 (2003). N.V. Mokhov, K.K. Gudima, C.C. James et al.,Fermilab-Conf-04/053(2004). http://www-ap.fnal.gov/MARS/

[6] http://mad.web.cern.ch/mad/mad8web/mad8.html

[7] T. Trenkler, J.B. Jeanneret, "K2: A Software Package evaluating Collimation Systems in

Circular Colliders (Manual)", SL/Note 94-105 (AP)
[8] F. Schmidt, "SixTrack. User's Reference Manual", CERN/SL/94-56(AP)
[9] G. Robert-Demolaize et al., "A New Version of Sixtrack with Collimation and Aperture Interface", CERN-AB-2005-033
[10] H. Grote, F. Schmidt, 2003 PAC Conference. MADX webpage http://mad.home.cern.ch
[11] Giovannozzi, Massimo (ed.) et al. , "The CERN PS multi-turn extraction based on beam splitting in stable islands of transverse phase space : Design Report", CERN-2006-01